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WATER USE INVENTORY REPORT

Hamaka Area Agricultural Water Study

UNITED STATES DEPARTMENT OF AGRICULTURE
Economics, Statistics, and Cooperative Service
Forest Service
Soil Conservation Service

STATE OF HAWAII
Department of Land and Natural Resources
Mauna Kea Soil and Water Conservation District

WATER USE INVENTORY REPORT

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INTRODUCTION

Purpose and Scope

The primary purpose of this report is to inventory the existing water use in the study area and to estimate the potential water demand for agricultural purposes. Data from this report and other special reports will be used to develop alternative solutions to the agricultural water problems in the area as identified in the Plan of Work.

A discussion is also included on the design of water harvesting catchments. The extent of future agricultural development is not known so the potential water demands are calculated on a per acre basis. The basic data is analyzed to the extent that areas that need irrigation water supply or livestock water development are identified and the minimum design capacities are listed.

Geographical and Historical Setting

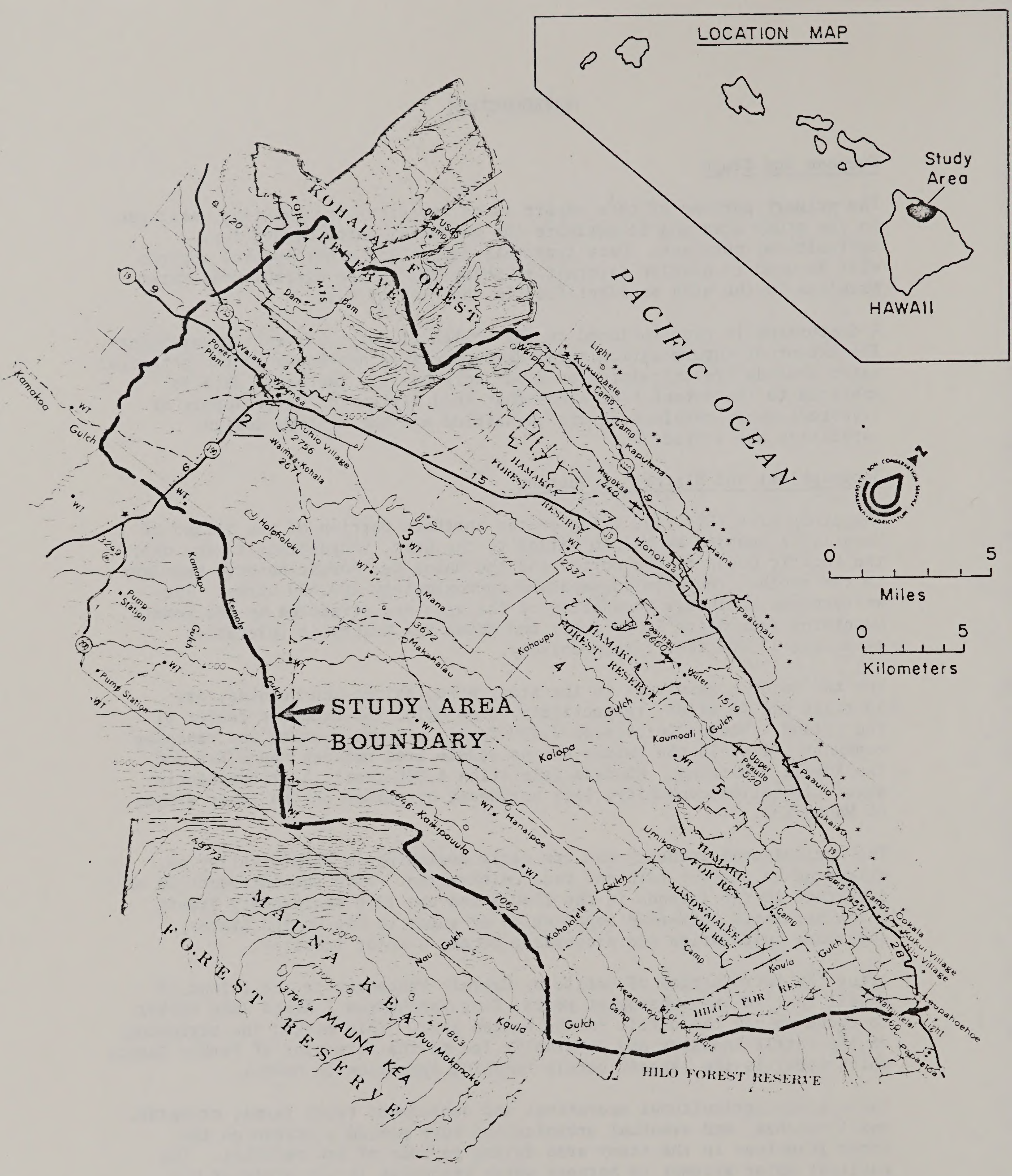
The study area (Fig. 1), lying on the northern portion of the island of Hawaii, is bounded by Waipio Valley to the west, Laupahoehoe to the east, the Pacific Ocean to the north, and the Mauna Kea Forest Reserve boundary to the south. The area encompasses approximately 200,000 acres. The western and southerly boundaries of the area are straddled by the Kohala Mountains (elevation 5,500 feet) and Mauna Kea Mountains (elevation exceeding 13,000 feet), respectively.

The two major communities in the study area, Waimea and Honokaa, are 58 miles and 43 miles, respectively, from Hilo, the economic center of the island. Waimea (elevation 2,800 feet), a rural farming and ranching community, lies in the Waimea plains saddle area between Mauna Kea and the Kohala Mountains. Honokaa (elevation 1,000 feet), a predominantly sugar plantation community, lies northeast of Waimea on the lower slopes of Mauna Kea.

The agricultural industry had its early beginning in Waipio Valley as evidenced by ancient taro and rice cultivation. With the introduction of sugarcane to the islands in the 1780's and the 1876 Reciprocity Treaty which permitted duty-free importation of sugar to the United States, sugarcane cultivation and processing became a major industry.

After the introduction of cattle by Captain Vancouver to the island of Hawaii in 1793 and subsequent years, King Kamehameha I hired John Parker to round up all the cattle in the Waimea area. This marked the beginning of the cattle industry and eventually led to the formation of Parker Ranch, which today is the largest cattle ranching operation in Hawaii.

These early agricultural operations and subsequent truck farms, orchards, small ranches, and eventual urbanization have placed a burden on the water resources in the study area during periods of low rainfall. The earliest major attempt to harness water resources in wet areas of the



LOCATION MAP

Hamakua Area Agricultural Water Study

Hamakua, Hawaii

Figure 1

Kohala Mountains to service other arid areas for agricultural purposes was the construction of the Upper and Lower Hamakua Ditches in 1910. Both of these systems tapped the abundant water resources in the Kohala Mountains and transported them via ditches to the sugarcane fields along the Hamakua Coast. Since that time, the State Department of Land and Natural Resources (DLNR) constructed the Lalamilo Irrigation System and Parker Ranch has installed a stockwater system, both of which derive water from the Kohala Mountains. The County of Hawaii's South Kohala Water System and Hamakua Water System also obtain domestic water from the Kohala Mountains.

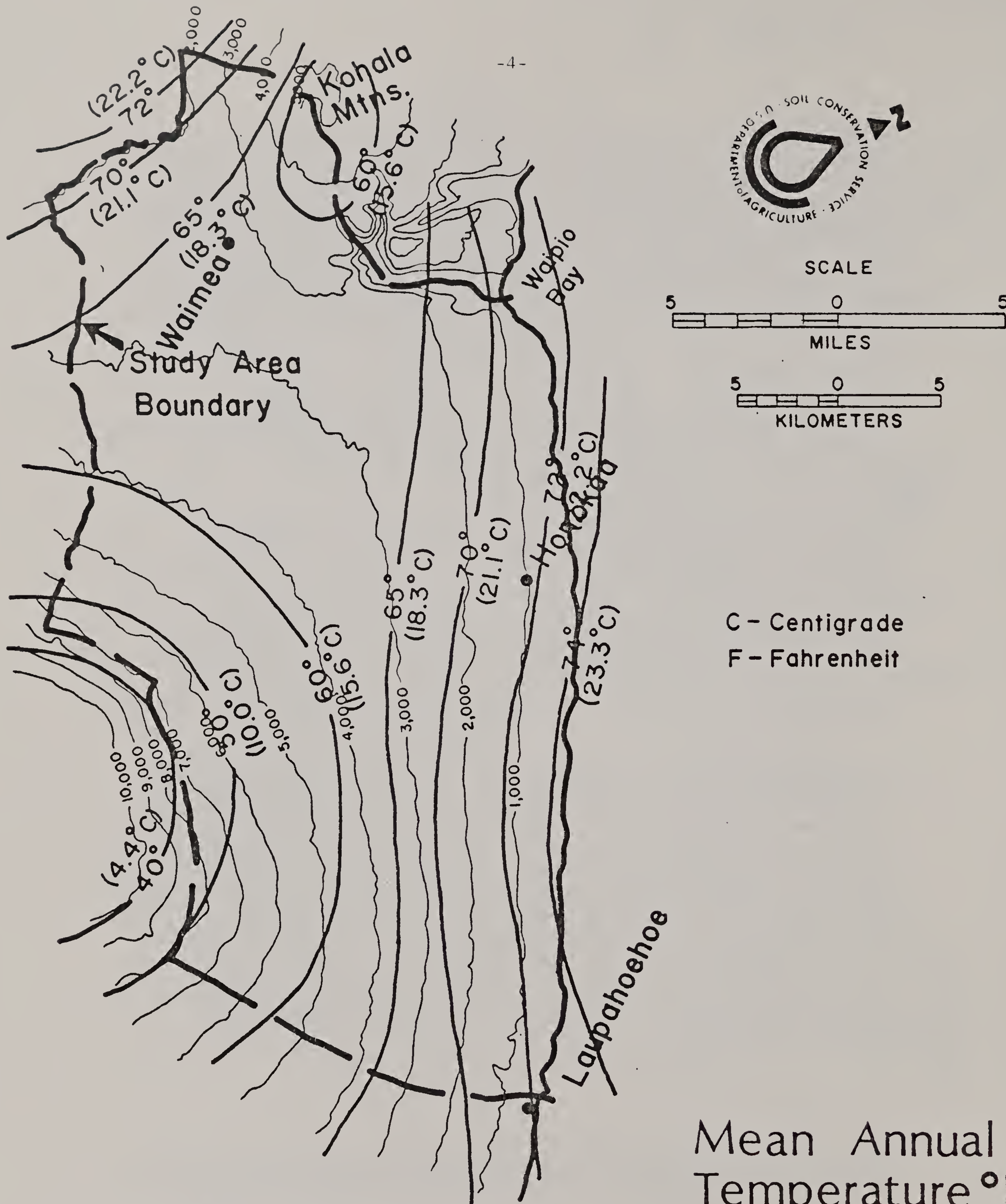
Climatic Conditions

The climate within the study area is characterized by moderate variations in annual temperature (Fig. 2), drastic variations in average annual rainfall (Fig. 3), and a prevailing northeast tradewind.

Both the relative constant length of daylight period and the slight variation in the altitude of the sun in Hawaii result in moderate variations in annual temperature (40° to 74°F) from one location to another within the study area. Temperature is primarily a function of elevation and records show that mean temperature decreases at an approximate rate of 1°F for each 300 feet increase in elevation, the rate being somewhat greater at lower elevations.1/ This constant rate of decrease exists up to approximately 5,000 to 7,000 feet elevations, at which point there is a temperature inversion or reversal and this rate subsequently decreases. This inversion serves as a ceiling for the tradewinds.

The rainfall variations throughout the study area are mainly due to the topography, tradewinds, and temperature. As moisture-laden tradewinds from the northeast ascend the slopes of Mauna Kea, they are cooled and release most of their moisture by elevation 3,000 feet. Annual rainfall varies from 60 inches along the coastline to 100 inches at elevation 3,000 feet and decreases to 20 inches at the southerly boundary of the study area (Fig.3). The ceiling or temperature inversion at 7,000 feet forces the tradewinds around Mauna Kea (elevation exceeding 13,000 feet) and over the Waimea Plains. The moisture laden tradewinds blow over the Kohala Mountains (elevation 5,500 feet) and this results in a high rainfall belt with a peak of 175 inches annually. Conversely, the tradewinds are impeded by the high peak of Mauna Kea in the Laupahoehoe and Ookala areas and this results in a high rainfall belt with a peak of 175 inches annually.

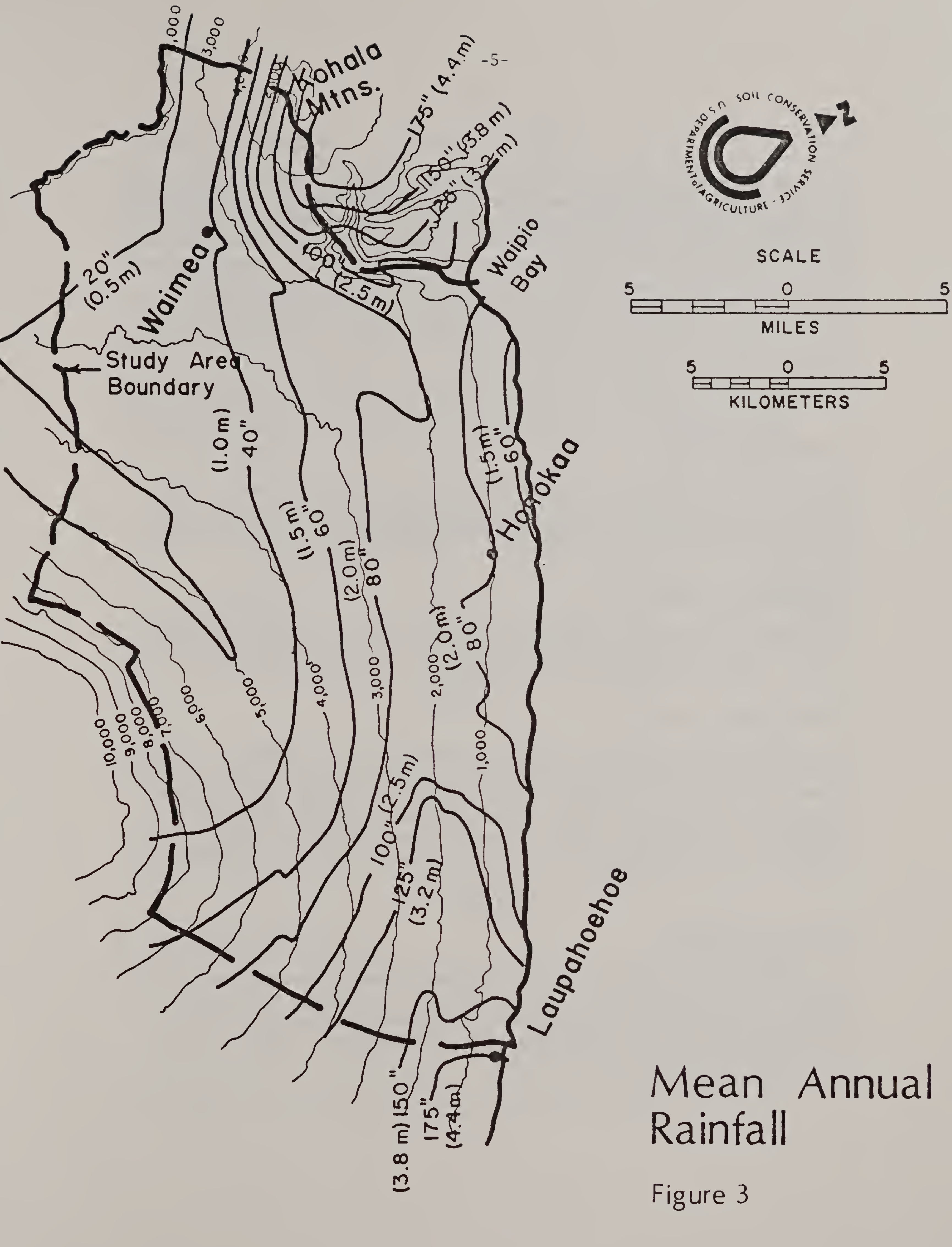
1/ Hawaii State Department of Land and Natural Resources, "An Inventory of Basic Water Resources Data, Island of Hawaii," Report R34, Page 83.



Source: An Inventory of Basic Water Resources Data:
Island of Hawaii Report R34
State of Hawaii, DLNR

Mean Annual Temperature °F

Figure 2



Mean Annual Rainfall

Figure 3

PRESENT WATER USE

Water is presently used in the study area from four main systems. They are the state water system administered by DLNR which provides water to the Lalamilo farmlots for irrigation, the County of Hawaii Department of Water Supply system which provides water throughout the study area for domestic use and also provides water for irrigation and livestock, the Hawaii Irrigation Company which is a private system that provides irrigation and industrial water to Davies-Hamakua Sugar Company, and Parker Ranch's private system for livestock water. In addition, many of the ranches in the study area have water harvesting catchments which provide additional water for livestock.

Irrigation

State Water System

Annual water consumption for irrigation in the Lalamilo farmlots was 59.8 MG in 1962 and has increased each year to 235.2 MG in 1978. The yearly increase results from more area being put into crop production each year. The peak daily use was 1.06 MGD in September 1978.

County Water System

The county water system provides irrigation water to farmers in the Puukapu homesteads, Hawaiian Homes farmlots, and Ahualoa and Paauilo areas. The annual irrigation consumption is estimated at 30 MG.

Private Water System

The largest user of water is the Davies-Hamakua Sugar Company. Their water requirements for 1979 were estimated as 4,680 MG. This estimate is based on 1,854 acres of drip irrigation and 5,041 acres of sprinkler irrigation. The sugar company plans on expanding their irrigated acreage to 7,959 acres by 1987. Their system has little storage and is limited in the summer months by the low flows in the Lower Hamakua Ditch.

Livestock

County Water System

The county water system discussed above also provides water for livestock through the Hawaiian Homes Ranch system, and to ranches in Pohakea, Ahualoa, Paauilo Mauka, and Honokaa. Some livestock water is pumped to elevations as high as 7,000 feet. The annual water consumption for livestock is estimated to be 13 MG.

Private Water System

The largest private livestock water system in the study area is the Parker Ranch system. This system is not metered so the annual consumption can only be estimated from the herd size. The estimated annual consumption is 154 MG. Part of this water is consumed outside of the study area.

The smaller private systems on ranches were not inventoried.

Total

The total present water use in the study area is summarized in Table 1. The total annual use is approximately 5,600 MG. Irrigation use accounts for approximately 88 percent of this use, domestic 9 percent, and livestock 3 percent.

TABLE 1

Present Water Use

System	Use	Annual Consumption MG	Peak Month Ave. Daily Consumption MGD
County	Domestic	(485)	-
	Irrigation	(30)	-
	Livestock	(13)	-
	Total	528	-
1/ State	Irrigation	235	1.1
2/ Private Davies-Hamakua Sugar	Irrigation	4,680	25.0
3/ Parker Ranch	Livestock	154	0.5
		5,597	

1/ Data for year 1978.
2/ Estimated use for 1979.
3/ System not metered, figures estimated from herd size, system also extends outside of study area.

POTENTIAL WATER DEMAND

Data on potential water demands was developed for irrigation of sugarcane, truck crops, and irrigated hay; and for livestock water.

This data is presented in a manner so it may be used for the design of alternative solutions. The annual volume per acre of water needed and how this volume is distributed per month is presented. With this data, the potential demand can be compared against the potential supply and the amount of storage needed, if any can be determined. Also shown is a peak demand for each use which can be used in determining capacity requirements.

The demand for irrigation or livestock water is dependent on rainfall. If the rainfall was sufficient and occurred at the right time, it would satisfy the water requirements of the plants and animals. Because rainfall does not always supply enough water, or at the right time, there exists a potential demand for water. These potential demands are thus related to the occurrence of rainfall.

Rainfall records from climatological stations can be analyzed statistically. It is possible to calculate the amount of rainfall that will occur annually for a given percent chance of occurrence. Agricultural water demands can then be calculated based on the amount of rainfall that will occur for a given percent chance of occurrence.

For this study irrigation water requirements were calculated for the annual rainfall that would occur 80 percent of the time, or 8 out of 10 years. Livestock water requirements were calculated for the annual rainfall that would occur 90 percent of the time, or 9 out of 10 years.

Irrigation

Methodology

The irrigation water requirements were calculated by estimating potential evapotranspiration, determining how much of the evapotranspiration will be satisfied by rainfall, and how much will be satisfied by irrigation.

The potential evapotranspiration was calculated at 110 rainfall stations in the study area using the modified Penman equation.2/ If temperature, humidity, or solar radiation data was not available at a rainfall station, it was estimated from available data.

The potential crop water requirements for sugarcane, truck crops, and irrigated hay were calculated from potential evapotranspiration at rainfall stations where these crops are or may be grown. The net irrigation requirements were determined for these crops by considering the portion of the potential crop water requirements that will be satisfied by rainfall. The gross irrigation requirements were determined from the net irrigation requirements for these crops considering the

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2/ Renner, Dean M., "Estimating Consumptive Use in Hawaii," Technical Note, Engineering No. 14, USDA-SCS, Honolulu, HI, April 1980.

field application efficiencies of irrigation. The gross irrigation requirements were calculated for each month and totaled to obtain the annual requirements.

The peak daily crop water requirements were determined from the month with the highest potential crop water requirements assuming no rainfall. The peak daily irrigation requirements were determined from the peak daily crop water requirements by considering the field application efficiencies of irrigation.

Sugarcane

Gross annual irrigation requirements for sugarcane in the study area vary from less than 10 inches per year (0.27 MG per acre per year) to greater than 35 inches per year (0.95 MG per acre per year). These values are for an 80 percent chance effective rainfall and assuming drip irrigation with a field application efficiency equal to 80 percent.

The gross annual irrigation requirements for sugarcane were plotted on 1:24,000 scale topographic maps. Reduced copies of these maps are in Appendix A, Figures A-1 through A-4. Full size copies of these maps are on file in the office of the Soil Conservation Service, River Basin and Watershed Planning Staff, Honolulu, HI.

The areas mapped for gross irrigation requirements for sugarcane exceed the existing irrigated areas for this crop. No attempt was made to delineate sugarcane areas that are not feasible for irrigation due to economic or other reasons.

The monthly gross irrigation requirements for sugarcane are shown in Table A-1, Appendix A. The monthly requirements are in million gallons (MG) per acre, per month, and are related to the values on the gross annual irrigation requirement maps.

The peak daily crop water requirements for 70, 80, and 90 percent efficiencies, and gross irrigation requirements for sugarcane in MGD per acre are shown in Table A-2, Appendix A. The peak daily values were related to the gross irrigation requirement maps, and the annual values shown on the maps.

The crop water requirements for sugarcane are a weighted average for the entire growing season. A 24-month growing season was assumed for irrigated sugarcane. The peak daily crop water requirements are also a weighted average for the entire growing season. This assumes that there is always sugarcane in all stages of growth, or that planting occurs all year-round. These values are for project design. For design of field systems, the peak daily crop water requirements would be based on mature cane during the warmest month.

Truck Crops

Gross annual irrigation requirements for truck crops in the study area vary from less than 15 inches per year (0.41 MG per acre, per year) to greater than 80 inches per year (2.17 MG per acre, per year). These values are for an 80 percent chance effective rainfall and assuming sprinkler irrigation with field application efficiencies from 60 to 65 percent.

The gross annual irrigation requirements for truck crops were plotted on 1:24,000 scale topographic maps. Reduced copies of these maps are in Appendix B, Figures B-1 through B-6. Full size copies of these maps are on file in the office of the Soil Conservation Service, River Basin and Watershed Planning Staff, Honolulu, HI.

The areas mapped for gross irrigation requirements for truck crops greatly exceed the present area devoted to this type of agricultural operation. This report does not reflect that the entire area mapped will eventually be in truck crops or is even suitable for truck crops. The maps in Appendix B show that the irrigation requirements would be for any truck crop operations in the study area.

The monthly gross irrigation requirements for truck crops are shown in Table B-1, Appendix B. The monthly requirements are in million gallons (MG) per acre, per month, and are related to the gross annual irrigation requirement maps and the values on these maps.

The peak daily crop water requirements for 50, 60 and 70 percent efficiency, in MGD per acre for truck crops are shown in Table B-2, Appendix B. The peak daily values were related to the gross irrigation requirement maps, and the annual values on the maps.

The crop water requirements for truck crops are a weighted average for the entire growing season. An 8- to 12-week growing period was used for each crop. The truck crop water requirements are for the area that is cropland not the area that is planted at any one time. The peak daily crop water requirements are also a weighted average for the entire growing season. This assumes that there are always truck crops in all stages of growth, or that planting and harvesting occurs year-round. These values can be used for project or individual farm system design.

Irrigated Hay

Potential gross annual irrigation requirements for irrigated hay in the study area vary from less than 20 inches per year (0.54 MG per acre, per year) to greater than 120 inches per year (3.26 MG per acre, per year). These values are for an 80 percent chance annual rainfall and assuming sprinkler irrigation with field application efficiencies from 60 to 70 percent.

The gross annual irrigation requirements for irrigated hay were plotted on 1:24,000 scale topographic maps. Reduced copies of these maps are in Appendix C, Figures C-1 through C-6. Full size copies of these maps are on file in the office of the Soil Conservation Service, River Basin and Watershed Planning Staff, Honolulu, HI.

There is presently no irrigated hay raised in the study area. However, some interest has been expressed in the crop and this analysis was made to show what the irrigation requirements would be. The areas mapped do not reflect that these areas will be converted to irrigated hay or that these areas are even suitable for this crop.

The monthly gross irrigation requirements for irrigated hay are shown in Table C-1, Appendix C. The monthly requirements are in million gallons (MG) per acre and are related to the gross annual irrigation requirement maps and the values on these maps.

The peak daily crop water requirements for 50, 60 and 70 percent efficiency, and gross irrigation requirements for irrigated hay in MGD per acre are shown in Table C-2, Appendix C. The peak daily values were related to the gross irrigation requirement maps, and the annual values on the maps.

The crop water requirements for irrigated hay were made assuming a mature crop with cutting or harvest approximately every four weeks. The monthly and annual gross irrigation requirements and peak daily crop water requirements are average values for what the crop needs are, considering that these needs would be low after a cutting and high before a cutting. The monthly and annual gross irrigation-requirement values can be used for project or individual farm-system designs. The peak daily crop water requirement values can only be used for project system design. For design of on-farm systems, a peak daily requirement based on the crop water requirements of a crop ready for cutting should be used.

Livestock Water

Methodology

The potential livestock water requirements for this report are expressed as gallons per acre. This figure was based on the water requirements for an individual animal and the area of pastureland required for each animal. Both of these figures depend on rainfall.

The relationship between annual rainfall and livestock water requirements for Hawaii is shown in Table 2.

TABLE 2

Livestock Water Requirements

Annual Rainfall	Daily Water Requirement per Animal
Less than 30 inches	Beef cattle and horses - 12 gallons
30 - 60 inches	Beef cattle and horses - 10 gallons
Over 60 inches	Beef cattle and horses - 8 gallons
All rainfall zones	Dairy cattle - 25 gallons
All rainfall zones	Sheep - 1 1/2 gallons

For this study, only water requirements for beef cattle and horses were used. The annual rainfall values in Table 3 were divided into monthly values and compared with the monthly rainfall values that would result in a 90 percent chance annual rainfall. The rainfall records at 72 climatological stations were analyzed and the daily water requirements per animal by month were calculated at each station.

The potential stocking rates or acreage required per animal were determined from information gathered during interviews with ranchers in the study area. These stocking rates were compared with annual rainfalls and a relationship was developed that is shown in Figure 4. The potential stocking rates are for the condition where the animals could have all the drinking water they need.

The potential stocking rate at each of the 72 climatological stations analyzed was determined from the mean annual rainfalls. The monthly and annual livestock water requirements at each rainfall station were then calculated in gallons per acre.

Results

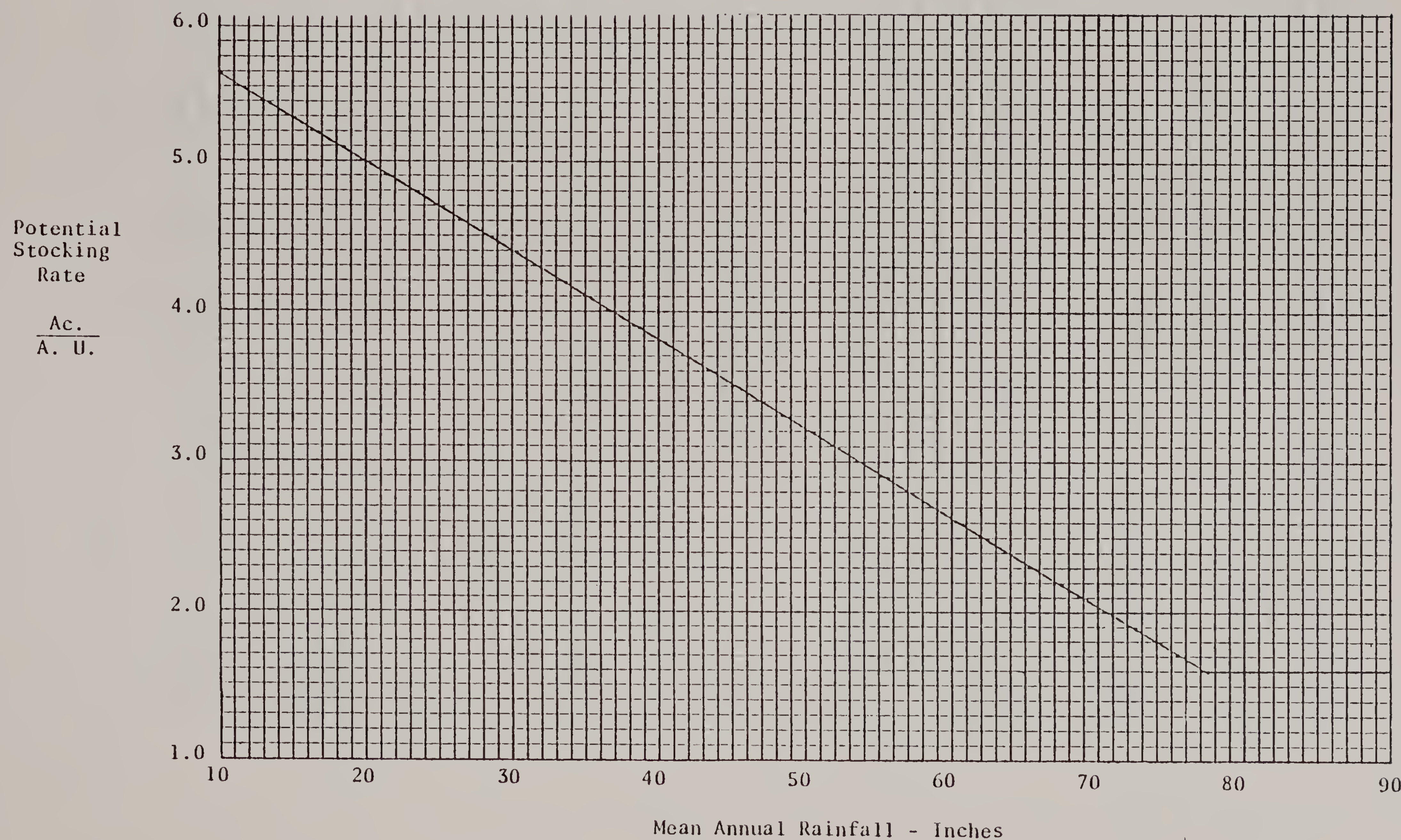
Potential annual livestock water requirements vary from less than 1,000 gallons per acre to more than 2,000 gallons per acre. These values are for a 90 percent chance annual rainfall.

The potential annual livestock water requirements were plotted on 1:24,000 scale topographic maps. Reduced copies of these maps are in Appendix D, Figures D-1 through D-7. Full size copies of these maps are on file in the office of the Soil Conservation Service, River Basin and Watershed Planning Staff, Honolulu, HI.

The potential monthly livestock water requirements are shown in Table D-1, Appendix D. The monthly requirements in Table D-1 are related to the annual water requirement maps and the values on these maps.

The peak daily livestock water requirements are shown in Table D-2. The peak daily rates are related to the annual livestock water requirement maps and the values on the maps.

Figure 4
Livestock Water Requirements
Potential Stocking Rate[1/] versus Mean Annual Rainfall



1/ Stocking rate represents water needs and does not represent needed level of grazing management.

The annual, monthly and peak daily livestock water requirements presented are based on stocking rates from Figure 4 and should only be used for project design analysis involving more than one ranch. Individual ranch water systems should be based on the stocking rates furnished by the ranch involved.

WATER DEVELOPMENT NEEDS

Irrigation

Sugarcane

There are approximately 35,720 acres of sugarcane within the study area of which 6,895 acres are presently irrigated. The present irrigation system is limited by the amount of water that is available in the Lower Hamakua Ditch during summer months. There is very little storage in the present system; therefore, the present system does not supply the total gross irrigation requirements that are presented in this report. The sugar company is presently converting from sprinkler irrigation to drip irrigation and has developed a conversion plan through year 1987. The calculated irrigation requirements for the present, planned, and potential irrigated acreage are shown in Table 3.

TABLE 3

Sugarcane Water Needs

80 Percent Chance Annual Rainfall

Area	Type of Irrigation	Gross Annual Irrigation Requirement	Field Application Efficiency (Percent)	Area Acre	Annual Irr. Req. MG/Yr.	Peak Irr. Req. MGD
Existing in 1979	Overhead		54	5,041	6,192	45.33
	Drip		80	1,854	1,472	11.08
	Total			6,895	7,664	56.41
Planned Improvements	Overhead		54	1,630	1,898	14.32
	Drip		80	6,329	5,005	38.19
	Total			7,959	6,903	52.51
Additional Sugarcane Land (presently not irr.)	Drip					
		35 in./yr.	80	114	108	0.73
		30-35 in./yr.	80	66	58	0.40
		25-30 in./yr.	80	873	655	5.19
		20-25 in./yr.	80	5,054	3,083	29.09
		15-20 in./yr.	80	8,456	4,059	46.21
		10-15 in./yr.	80	6,186	2,103	32.87
		5-10 in./yr.	80	4,982	996	25.76
		5 in./yr.	80	2,030	284	9.74
	Total			27,761	11,346	149.99

The planned conversion to drip irrigation results in the decrease in gross irrigation requirement of 761 MG with an increase in irrigated area of 1,064 acres.

Comparing the irrigation requirement figures in Table 3 with the present water use for sugarcane of 4,680 MG annual and 25.0 MGD peak daily show the need for additional water for the present system.

If there was more water available for irrigation, more sugarcane could be irrigated. The sugar company estimates that at least another 2,000 acres could be irrigated. Also, there are over 3,000 acres of sugarcane owned by independent growers and much of this land could be irrigated.

The total area of sugarcane that could be irrigated is not known at this time because the economics of sugarcane irrigation is not well defined. Theoretically, the entire 35,720 acres of sugarcane could be irrigated, but the cost of installing and operating an irrigation system may be more than the beneficial returns from it in the higher rainfall areas. Table 3 lists the irrigation requirements for the 27,761 acres of sugarcane that is not presently planned to be put under irrigation. The water requirements for this nonirrigated sugarcane land are broken down by annual depth of application required for drip irrigation.

In summary, the water development needs for sugarcane are:

1. Develop more water for presently irrigated area to supplement supply from the Lower Hamakua Ditch.

2. Develop systems to bring irrigation water to sugarcane lands that are not presently irrigated but would benefit from irrigation.

Truck Crops

The state agricultural water system serves only the Lalamilo farmlots; the farmlots in the Puukapu and Hawaiian Homes areas presently use domestic water for irrigation. Other areas where truck crops are grown also use domestic water for irrigation.

Table 4 shows the calculated irrigation requirements for existing, planned, and potential truck crop areas. The existing, planned, and potential acreage in truck crops are difficult to determine due to the many small operations, year-round harvesting and planting, and constantly changing economic conditions. It was estimated that presently there are approximately 464 acres cultivated for truck crops.

The present field application efficiency is estimated to be 55 percent. By improving the on-farm irrigation systems, installing more windbreaks, and using different management techniques, the average field application efficiency may be raised to 60 percent.

The state is presently planning to expand the Lalamilo farmlots with an agricultural park of approximately 450 acres. This expansion will be done in two phases. This may increase the cultivated truck crop area by 163 acres in the first phase of the expansion. An estimated 125 acres may be cultivated in the second phase.

The cultivated acreage in the Puukapu-Hawaiian Homes area may expand to an estimated 404 acres.

TABLE 4

Truck Crop Water Needs

80 Percent Chance Annual Rainfall

Systems	Field Application Efficiency (Percent)	Cultivated Area (Acre)	Annual Irr. Req. (MG/Yr.)	Peak Irr. Req. (MGD)
Existing in 1979				
Lalamilo Ag Park	55	230	518	2.12
Puukapu-Hawaiian Homes	55	234	324	1.76
Total		464	842	3.88
Existing - Improved				
Lalamilo Ag Park - (1)	60	250	518	2.12
Puukapu-Hawaiian Homes (3)	60	255	324	1.76
Total		505	842	3.88
Planned Expansion				
Lalamilo Ag Park -				
Phase I expansion	60	163	356	1.40
Phase II expansion	60	125	273	1.07
Total Lalamilo Ag Park (2)		288	629	2.47
Puukapu-Hawaiian Homes (4)	60	404	533	2.84
Total Lalamilo Ag Park (1+2)		538	1,147	4.59
Total Puukapu-Hawaiian Homes (3+4)		659	857	4.60
Total		1,197	2,004	9.19
Potential New Areas				
Undetermined locations	60	539	968	4.25
TOTAL		1,736	2,972	13.44

The potential new areas are assumed to be located in the Lalamilo and Puukapu-Hawaiian Homes vicinities.

There may be a potential for truck crops in the Ahualoa and Paauilo areas. These areas are presently served by the county domestic system. A determination is needed of the amount of land that may potentially be in truck crops in these and any other locations before any additional irrigation needs can be determined. If there is a demand for irrigation water in these areas an agricultural water system should be installed.

In summary, the water development needs for truck crops are:

1. Develop a system to provide irrigation water to the Puukapu and Hawaiian Homes farms presently using domestic water for irrigation.

2. Supply irrigation water to existing and proposed expansion of Lalamilo and Hawaiian Homes farmlots.

3. Supply irrigation water to any potential new truck crop areas.

Irrigated Hay

There is presently no irrigated hay in the study area. A determination is needed of the area that may potentially be used for this crop before the water demand can be determined. There is presently no system which would be adequate to provide irrigation water for a large area of irrigated hay.

Livestock Water

There are presently three sources of livestock water: the county domestic system, the Parker Ranch system, and small water harvesting catchments on individual ranches. The livestock water needs were studied on 121,230 acres of the 122,620 acres of pastureland in the study area. Table 5 shows the calculated livestock water requirements for the present sources.

TABLE 5

Livestock Water Needs

90 Percent Chance Annual Rainfall

Water Source	Area Acre	Annual Water Req. MG/Yr.	Peak Water Req. MGD
County System and Catchments	68,460	101	0.34
Parker Ranch System	52,770	59	0.17
Total	121,230	160	0.51

The county domestic system is presently not adequate to supply the livestock water needed. Most of the pastures are at elevations higher than the county system; therefore, pumping stations are needed. An agricultural water system is needed to provide livestock water to all pasturelands which presently receive water from the county domestic system.

The Parker Ranch system also may not be adequate to supply all the water needed by the ranch. Parker Ranch could use additional livestock water in the study area.

No inventory has been made of the small water harvesting catchments on individual ranches. These installations have been made to supplement the county system as a source. The following section on water harvesting catchments describes material that can be used in evaluating these rainfall catchments.

In summary, the water development needs for livestock water are:

1. Develop a system to provide water to all pasturelands which presently use domestic water for livestock.

2. Provide water to supplement the Parker Ranch system.

WATER HARVESTING CATCHMENTS

Water harvesting catchments are an alternative water source to diverting surface water or tapping subsurface reservoirs. A water harvesting catchment is simply a means to collect and store rainfall. It consists of a catchment area and a storage facility. The catchment area is an area that is paved or lined, or it may be a roof. The storage facility is usually a tank or pond.

The most important consideration in a water harvesting system is the dependability of the water supply. The storage facility must be large enough to carry a supply of water through a period of no rainfall. The catchment area should be large enough to insure the storage facility is refilled considering the rate of use from storage and local rainfall patterns.

To provide criteria for designing and evaluating water harvesting catchments, data from six long-term rainfall stations were evaluated using criteria developed by the Agricultural Research Service.[3/] The result of this analysis is presented in Appendix E.

3/ Ree, W. O., F. L. Wimberley, W. R. Gwinn, and C. W. Lauritzen, "Rainfall Harvesting System Design," ARS Publication 41-184, Agricultural Research Service, USDA, July 1971.

APPENDIX A

SUGARCANE IRRIGATION WATER REQUIREMENTS

TABLE A-1

Sugarcane
Gross Irrigation Requirements - Monthly Distribution
80 Percent Chance Annual Rainfall

Quad.	Annual Irr. Req.		Monthly Gross Irrigation Requirement MG/Ac.											
Sheet	In./Yr.	MG/Ac./Yr.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
H-35	10	0.27	0	0	0	0	0.02	0.07	0.04	0.04	0.08	0.03	0	0
(Fig. A-1)	15	0.41	0	0	0	0	0.06	0.08	0.07	0.04	0.09	0.07	0	0
	20	0.54	0.01	0	0.01	0	0.07	0.11	0.09	0.08	0.11	0.06	0.01	0
	25	0.68	0.01	0.01	0.01	0.02	0.09	0.12	0.11	0.11	0.12	0.07	0.01	0
	30	0.81	0.03	0.03	0.02	0.03	0.10	0.13	0.12	0.12	0.13	0.08	0.03	0
	35	0.95	0.03	0.03	0.04	0.05	0.11	0.14	0.13	0.13	0.14	0.09	0.04	0.02
H-44	15	0.41	0	0	0	0	0.05	0.10	0.08	0.04	0.09	0.05	0	0
(Fig. A-2)	20	0.54	0	0	0	0	0.07	0.12	0.10	0.07	0.10	0.06	0.03	0
	25	0.68	0	0	0.01	0	0.09	0.15	0.13	0.09	0.13	0.07	0	0
	30	0.81	0.02	0.01	0.02	0.03	0.10	0.15	0.14	0.10	0.13	0.09	0.03	0
	35	0.95	0.02	0.03	0.03	0.05	0.13	0.16	0.15	0.13	0.14	0.10	0.01	0
H-52	10	0.27	0	0	0	0	0.01	0.09	0.05	0.01	0.08	0.03	0	0
(Fig. A-3)	15	0.41	0	0	0	0	0.04	0.12	0.06	0.05	0.09	0.04	0	0
	20	0.54	0.01	0.01	0	0	0.07	0.13	0.08	0.07	0.11	0.06	0	0
	25	0.68	0.03	0.02	0	0.02	0.08	0.14	0.10	0.09	0.13	0.06	0.02	0
	30	0.81	0.04	0.02	0	0.03	0.09	0.17	0.12	0.10	0.15	0.07	0.02	0
H-53	5	0.14	0	0	0	0	0	0.07	0.01	0	0.06	0	0	0
(Fig. A-4	10	0.27	0	0	0	0	0.02	0.09	0.05	0.02	0.07	0.02	0	0

TABLE A-2

Sugarcane
Peak Daily Crop Water and Gross Irrigation Requirements

Quad Sheet	Gross Annual Irrigation Requirements In./Yr.	Gross Annual Irrigation Requirements MG/Ac./Yr.	Peak Daily ET Crop MGD/Ac.	Peak Daily Irrigation Requirements MGD/Ac. Percent Efficiency 70	80	90
H-35	10	0.27	0.0038	0.0054	0.0048	0.0042
(Fig. A-1)	15	0.41	0.0042	0.0060	0.0053	0.0047
	20	0.54	0.0045	0.0064	0.0056	0.0050
	25	0.68	0.0046	0.0066	0.0058	0.0051
	30	0.81	0.0048	0.0068	0.0060	0.0053
	35	0.95	0.0051	0.0073	0.0064	0.0057
H-44	15	0.41	0.0040	0.0057	0.0050	0.0044
(Fig. A-2)	20	0.54	0.0045	0.0064	0.0056	0.0050
	25	0.68	0.0047	0.0067	0.0059	0.0052
	30	0.81	0.0048	0.0068	0.0060	0.0053
	35	0.95	0.0051	0.0073	0.0064	0.0057
H-52	10	0.27	0.0043	0.0061	0.0054	0.0048
(Fig. A-3)	15	0.41	0.0045	0.0064	0.0056	0.0050
	20	0.54	0.0048	0.0068	0.0060	0.0053
	25	0.68	0.0050	0.0071	0.0063	0.0056
	30	0.81	0.0050	0.0071	0.0063	0.0056
H-53	5	0.14	0.0038	0.0054	0.0048	0.0042
(Fig. A-4)	10	0.27	0.0038	0.0054	0.0048	0.0042

Fig. A-4


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
KEANAKOLU QUADRANGLE
HAWAII–ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
5 In/yr 0.14 MG/Ac/yr
10 in/yr 0.27 MG/Ac/yr
HAMAKUA FOREST RESERVE
MANOWAIALEE
FOREST
RESERVE
HILO
FOREST
RESERVE
Fig. A-4
Sugarcane
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall

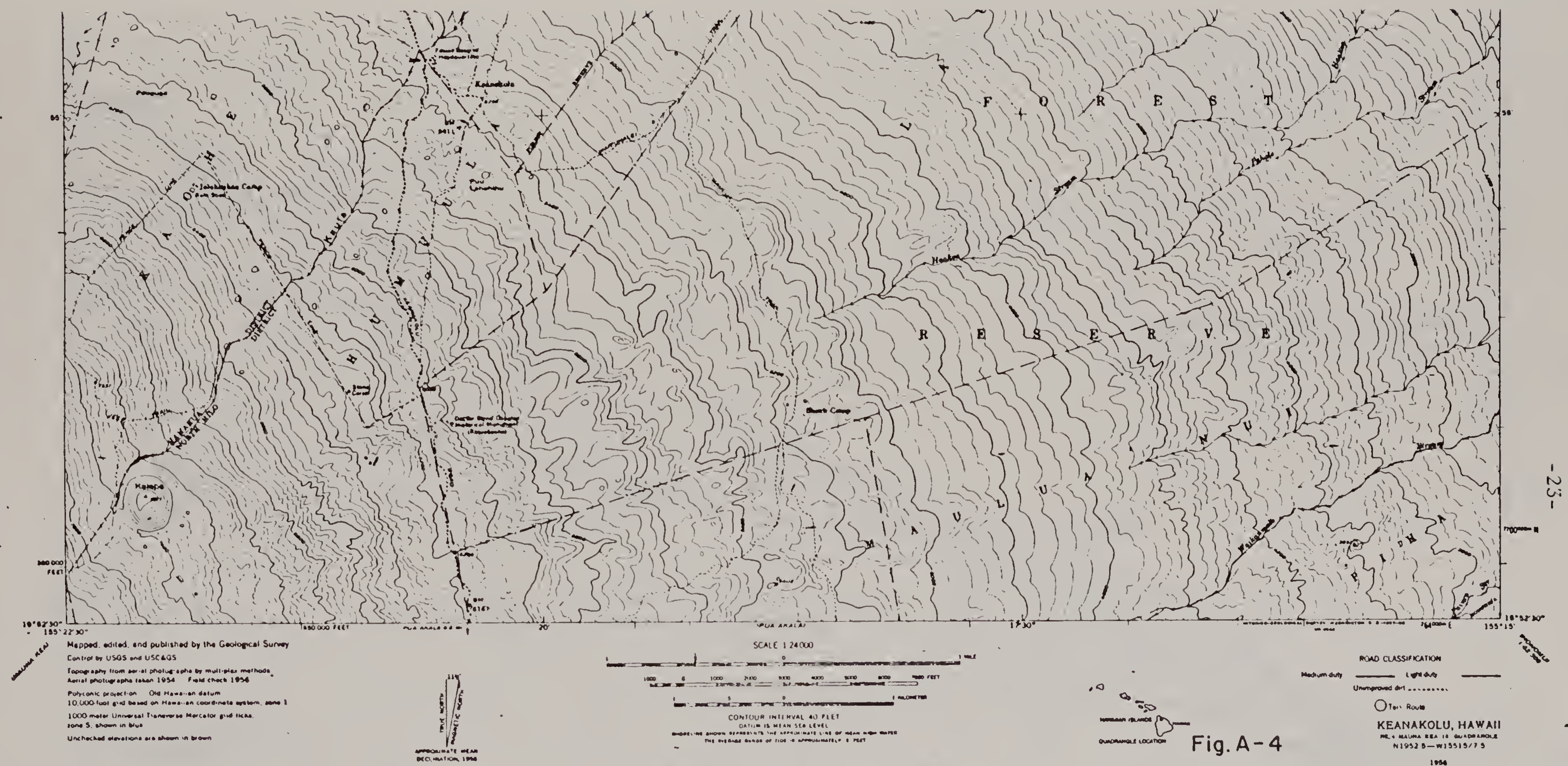
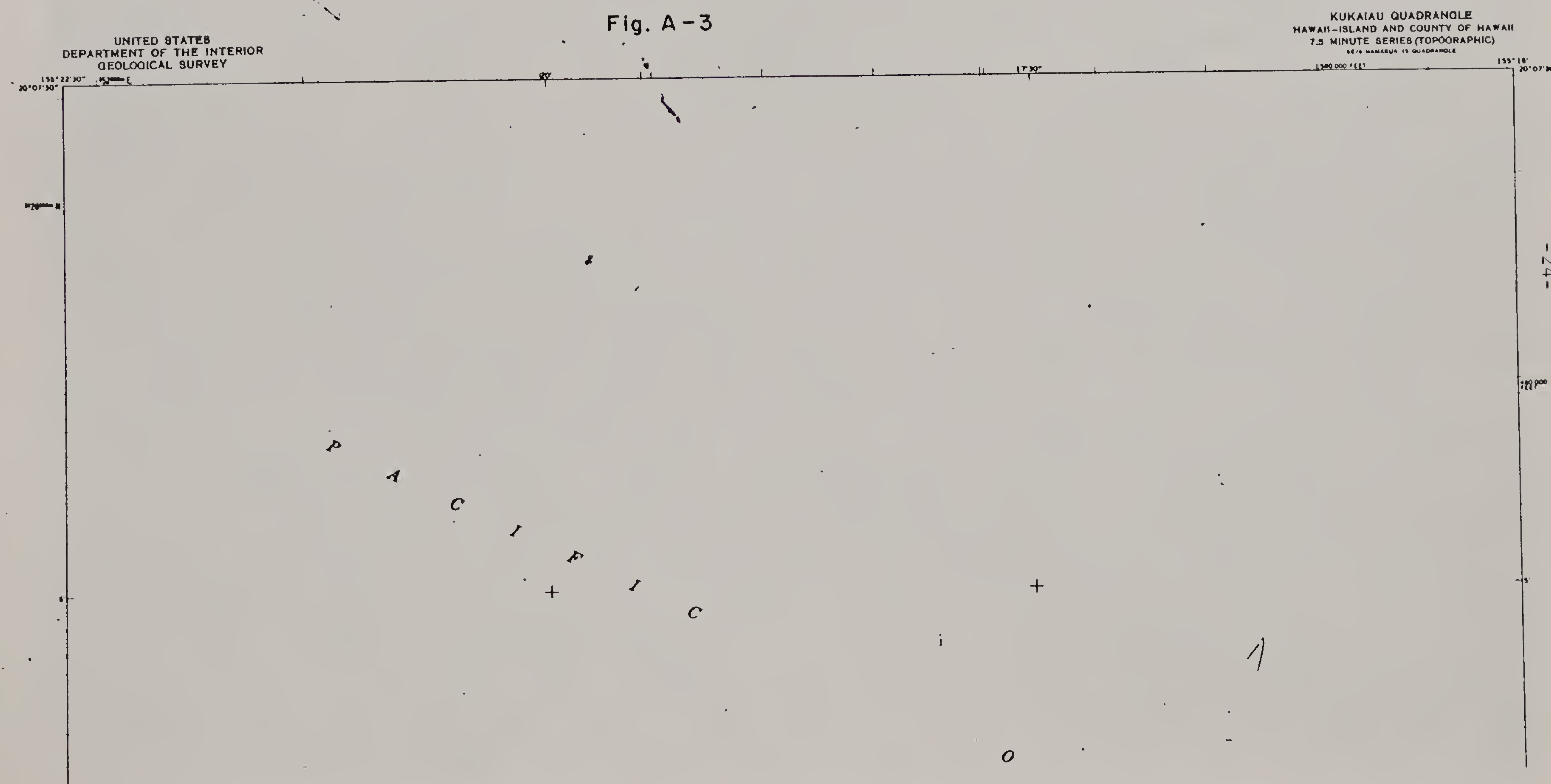


Fig. A-4

H-53

H-53

Fig. A-3


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
KUKAIAU QUADRANGLE
HAWAII-ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
155°22'30"
20°07'30"
17'30"
155°15'
20°07'30"
P A C I F I C
O

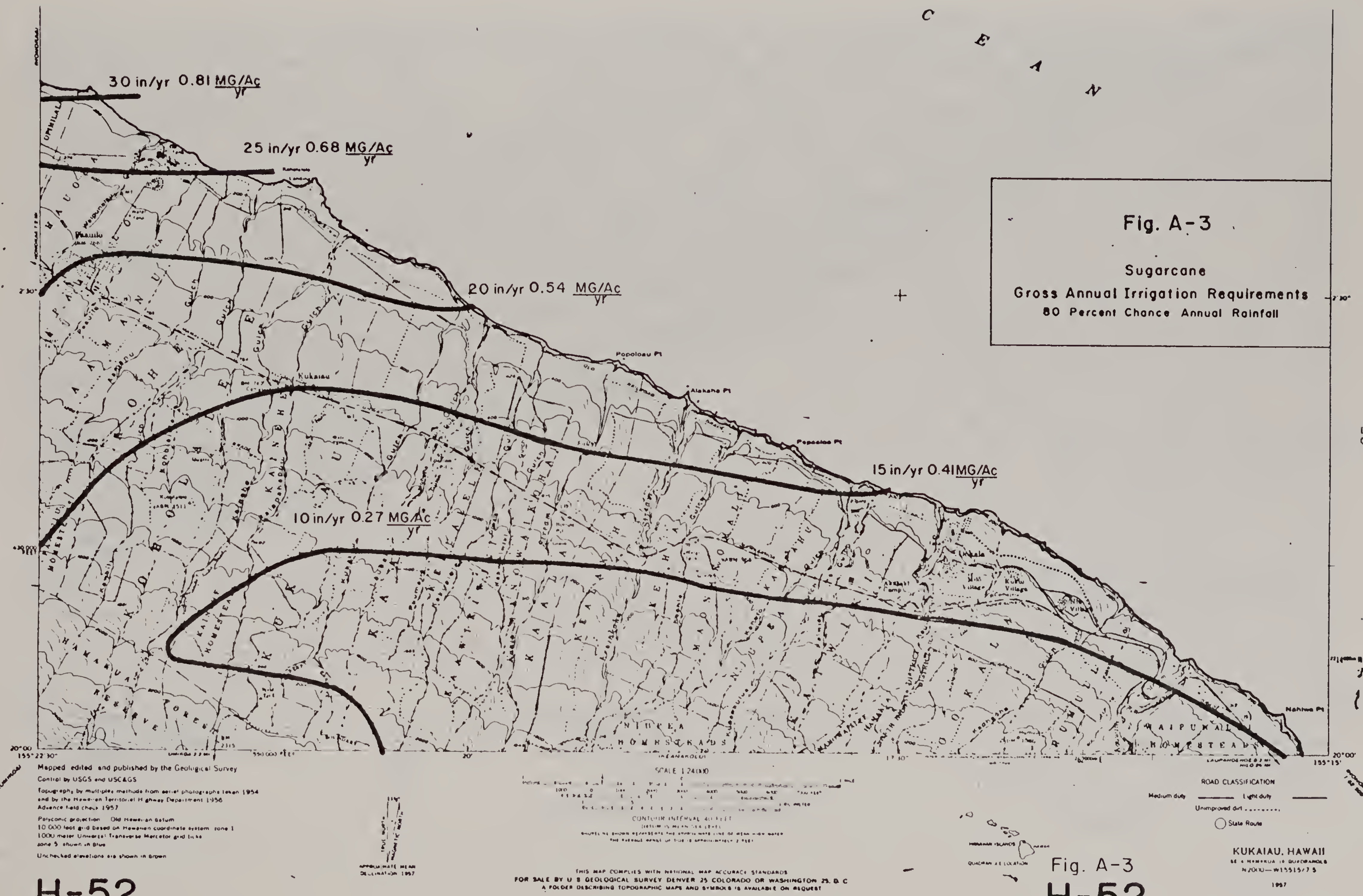


Fig. A-3

Sugarcane

Gross Annual Irrigation Requirements

80 Percent Chance Annual Rainfall

H-52

Fig. A-3

H-52

Fig. A-2

Sugarcane

Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall

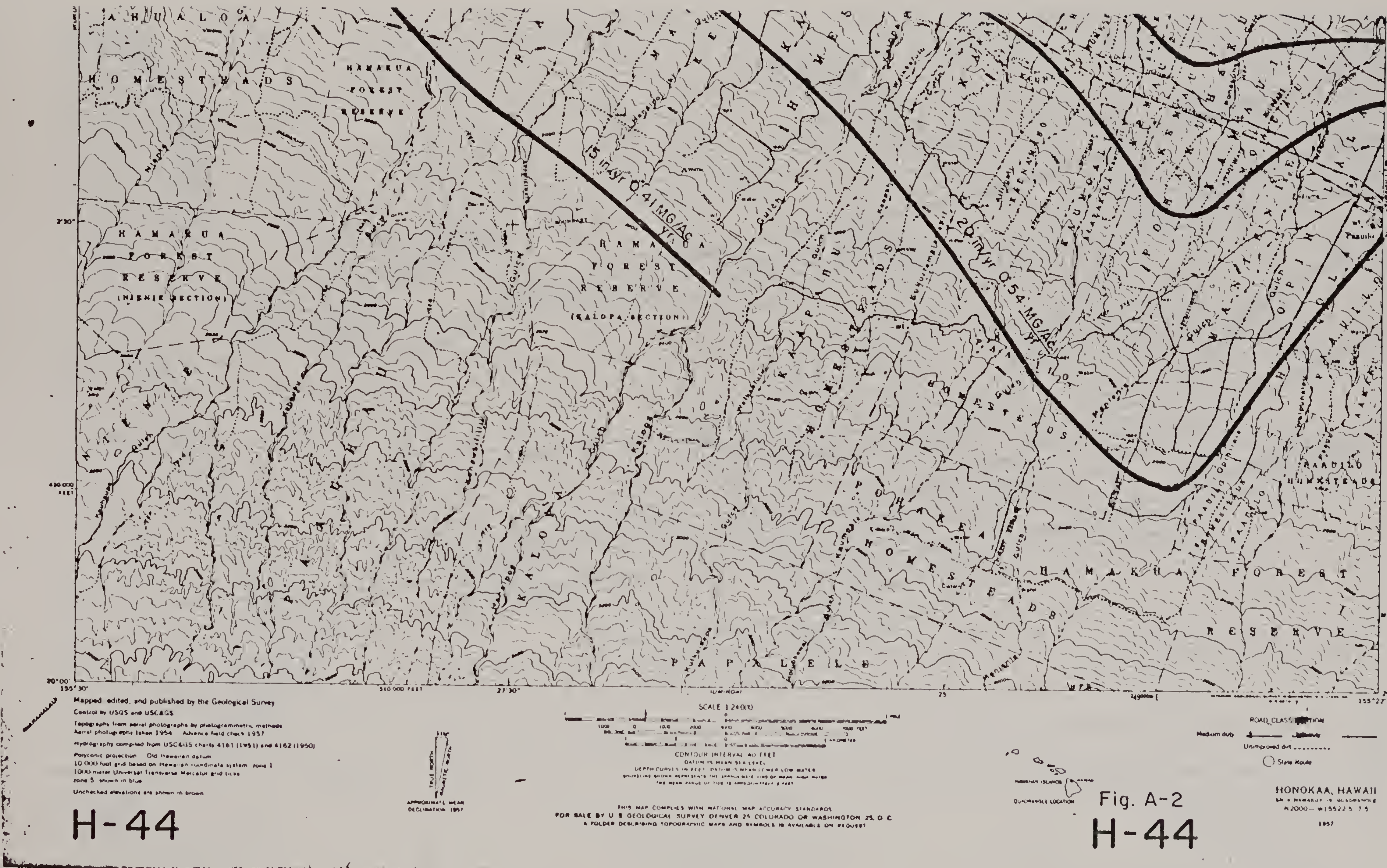

15 in/yr 0.41 MG/Ac/Yr
20 in/yr 0.54 MG/Ac/Yr
AHUALOA
HOMESTEADS
HAMAKUA FOREST RESERVE
HAMAKUA FOREST RESERVE (NIENIE SECTION)
HAMAKUA FOREST RESERVE (KALOPA SECTION)
HAMAKUA FOREST RESERVE
PAPALELE
PAAUILO HOMESTEADS
Paauilo
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1954. Advance field check 1957
Hydrography compiled from USC&GS charts 4161 (1951) and 4162 (1950)
Polyconic projection. Old Hawaiian datum
10,000-foot grid based on Hawaiian coordinate system, zone 1
1000-meter Universal Transverse Mercator grid ticks, zone 5, shown in blue
Unchecked elevations are shown in brown
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER 25, COLORADO OR WASHINGTON 25, D.C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
ROAD CLASSIFICATION
Medium duty
Unimproved dirt
State Route
QUADRANGLE LOCATION
HONOKAA, HAWAII
1957
H-44

Fig. A-2

H-44

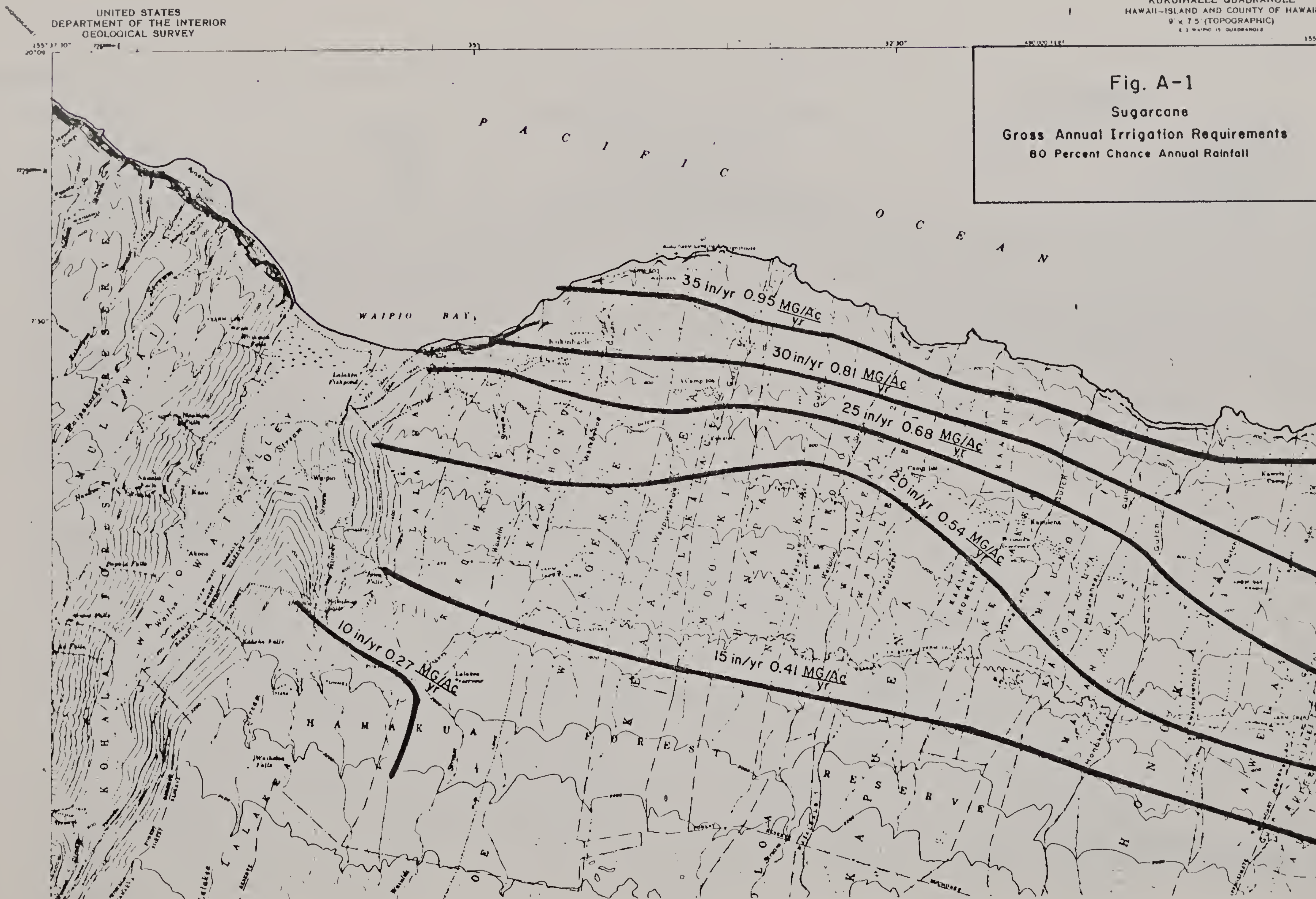
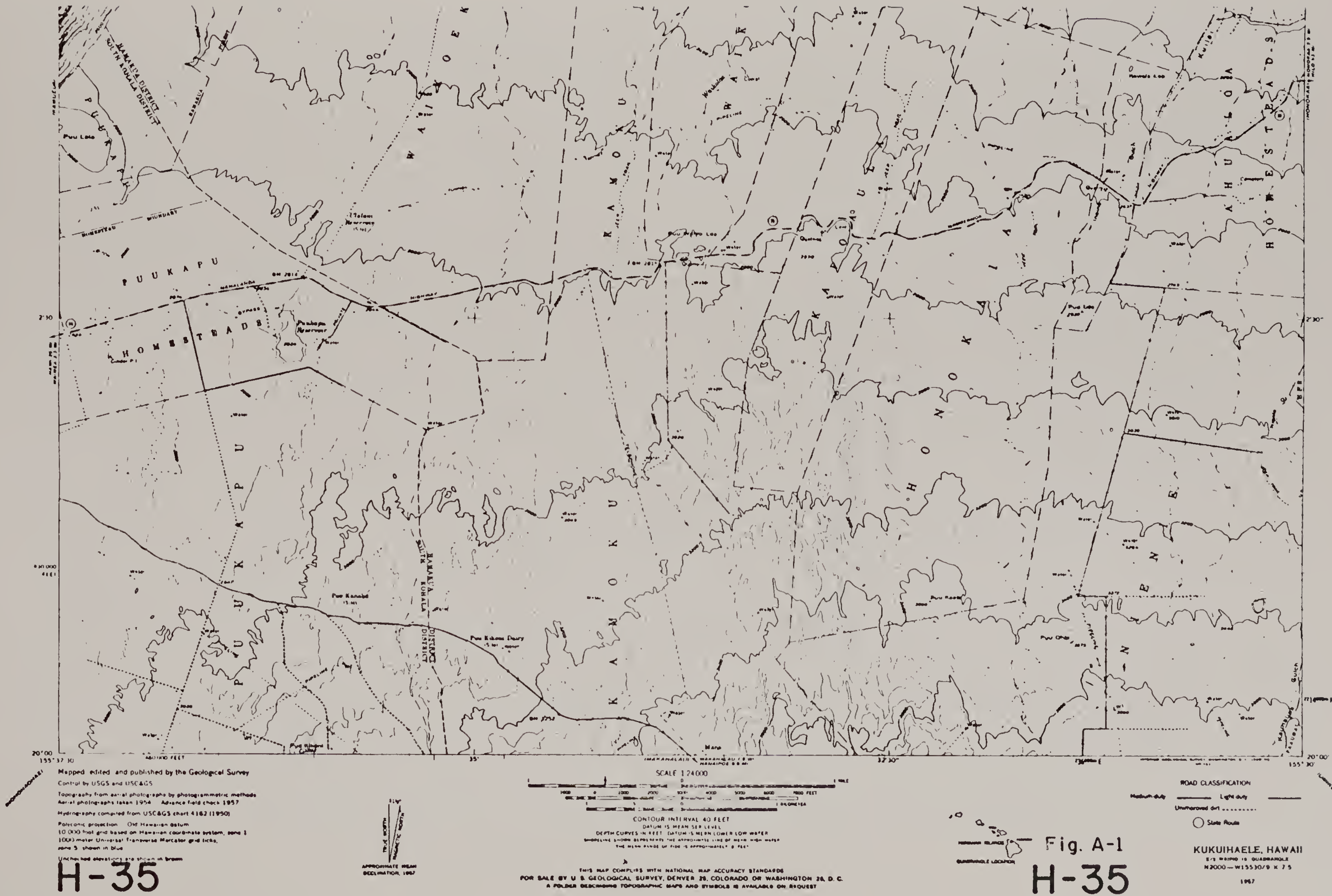


Fig. A-1
Sugarcane
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall



H-35

Fig. A-1

H-35

APPENDIX B

TRUCK CROP IRRIGATION WATER REQUIREMENTS

TABLE B-1
Truck Crops
Gross Irrigation Requirements - Monthly Distribution
80 Percent Chance Annual Rainfall

Quad. Sheet	Annual Irr. Req.		Monthly Gross Irrigation Requirement MG/Ac.											
	In./Yr.	MG/Ac./Yr.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
H-25	20	0.54	0	0	0.01	0	0.08	0.10	0.09	0.09	0.09	0.07	0.01	0
(Fig. B-1)	30	0.81	0.01	0.02	0.03	0.02	0.10	0.12	0.11	0.12	0.13	0.09	0.04	0.02
	40	1.09	0.03	0.06	0.06	0.09	0.11	0.15	0.13	0.11	0.13	0.10	0.07	0.03
	50	1.36	0.05	0.08	0.10	0.12	0.14	0.17	0.16	0.14	0.15	0.12	0.08	0.05
	60	1.63	0.06	0.09	0.12	0.15	0.17	0.20	0.19	0.16	0.18	0.14	0.10	0.07
	70	1.90	0.06	0.12	0.15	0.16	0.20	0.23	0.22	0.19	0.20	0.17	0.11	0.09
	80	2.17	0.09	0.14	0.18	0.19	0.22	0.25	0.24	0.21	0.21	0.18	0.14	0.12
H-26	60	1.63	0.04	0.09	0.14	0.16	0.17	0.19	0.19	0.18	0.15	0.14	0.09	0.09
(Fig. B-2)	70	1.90	0.07	0.11	0.16	0.18	0.19	0.22	0.22	0.20	0.17	0.16	0.11	0.11
	80	2.17	0.10	0.13	0.16	0.20	0.21	0.24	0.25	0.21	0.21	0.18	0.15	0.13
H-35	15	0.41	0	0	0	0	0.05	0.08	0.08	0.06	0.10	0.04	0	0
(Fig. B-3)	20	0.54	0	0	0.01	0.01	0.07	0.10	0.09	0.08	0.11	0.06	0.01	0
	30	0.81	0.02	0.03	0.04	0.05	0.09	0.11	0.11	0.11	0.11	0.09	0.04	0.01
	40	1.09	0.04	0.05	0.07	0.08	0.12	0.13	0.13	0.13	0.13	0.11	0.07	0.03
	50	1.36	0.05	0.06	0.08	0.09	0.14	0.17	0.17	0.17	0.17	0.13	0.08	0.05
	60	1.63	0.08	0.09	0.11	0.11	0.17	0.19	0.19	0.19	0.18	0.14	0.10	0.08
H-36	40	1.09	0.04	0.05	0.07	0.08	0.13	0.15	0.15	0.12	0.14	0.08	0.06	0.02
(Fig. B-4)	50	1.36	0.06	0.07	0.09	0.10	0.15	0.17	0.17	0.14	0.16	0.11	0.09	0.05
	60	1.63	0.08	0.09	0.11	0.11	0.17	0.19	0.19	0.19	0.18	0.14	0.10	0.08
	70	1.90	0.09	0.12	0.14	0.15	0.19	0.22	0.21	0.19	0.20	0.16	0.12	0.11
	80	2.17	0.11	0.14	0.17	0.19	0.21	0.25	0.24	0.20	0.21	0.18	0.14	0.13
H-44	15	0.41	0	0	0	0	0.05	0.11	0.07	0.05	0.08	0.05	0	0
(Fig. B-5)	20	0.54	0	0	0	0	0.07	0.13	0.11	0.07	0.10	0.06	0	0
	30	0.81	0	0.01	0	0.03	0.12	0.16	0.13	0.11	0.15	0.08	0.02	0
	40	1.09	0.01	0.03	0.01	0.06	0.15	0.20	0.16	0.13	0.18	0.10	0.05	0.01
H-45	20	0.54	0	0	0	0	0.08	0.13	0.09	0.08	0.10	0.06	0	0
(Fig. B-6)	30	0.81	0.03	0.02	0.03	0.05	0.10	0.14	0.11	0.11	0.12	0.07	0.02	0.01
	40	1.09	0.05	0.04	0.05	0.07	0.12	0.17	0.14	0.14	0.15	0.10	0.04	0.02
	50	1.36	0.08	0.06	0.07	0.09	0.15	0.20	0.16	0.16	0.17	0.12	0.06	0.04
	60	1.63	0.10	0.09	0.10	0.11	0.17	0.21	0.18	0.18	0.19	0.14	0.09	0.07
	70	1.90	0.11	0.11	0.13	0.14	0.19	0.23	0.20	0.21	0.20	0.15	0.12	0.11

TABLE B-2

Truck Crops
Peak Daily Crop Water and Gross Irrigation Requirements

Quad. Sheet	Gross Annual Irr. Req. In./Yr.	Gross Annual Irr. Req. MG/Ac./Yr.	Peak Daily ET Crop MGD/Ac.	Peak Daily Irr. Req. MGD/Ac. Percent Efficiency 50	60	70
H-25	20	0.54	0.0036	0.0072	0.0060	0.0051
(Fig. B-1)	30	0.81	0.0038	0.0076	0.0063	0.0054
	40	1.09	0.0039	0.0078	0.0065	0.0056
	50	1.36	0.0042	0.0084	0.0070	0.0060
	60	1.63	0.0048	0.0096	0.0080	0.0068
	70	1.90	0.0049	0.0098	0.0082	0.0070
	80	2.17	0.0052	0.0104	0.0087	0.0074
H-26	60	1.63	0.0045	0.0090	0.0075	0.0064
(Fig. B-2)	70	1.90	0.0048	0.0096	0.0080	0.0068
	80	2.17	0.0051	0.0102	0.0085	0.0073
H-35	15	0.41	0.0036	0.0072	0.0060	0.0051
(Fig. B-3)	20	0.54	0.0038	0.0076	0.0063	0.0054
	30	0.81	0.0040	0.0080	0.0067	0.0057
	40	1.09	0.0042	0.0084	0.0070	0.0060
	50	1.36	0.0045	0.0090	0.0075	0.0064
	60	1.63	0.0047	0.0094	0.0078	0.0067
H-36	40	1.09	0.0039	0.0078	0.0065	0.0056
(Fig. B-4)	50	1.36	0.0042	0.0084	0.0070	0.0060
	60	1.63	0.0046	0.0092	0.0077	0.0066
	70	1.90	0.0049	0.0098	0.0082	0.0070
	80	2.17	0.0052	0.0104	0.0087	0.0074
H-44	15	0.41	0.0037	0.0074	0.0062	0.0053
(Fig. B-5)	20	0.54	0.0039	0.0078	0.0065	0.0056
	30	0.81	0.0043	0.0086	0.0072	0.0061
	40	1.09	0.0046	0.0092	0.0077	0.0066
H-45	20	0.54	0.0035	0.0070	0.0058	0.0050
(Fig. B-6)	30	0.81	0.0041	0.0082	0.0068	0.0058
	40	1.09	0.0043	0.0086	0.0072	0.0061
	50	1.36	0.0044	0.0088	0.0073	0.0063
	60	1.63	0.0046	0.0092	0.0077	0.0066
	70	1.90	0.0048	0.0096	0.0080	0.0068


KAMUELA QUADRANGLE
HAWAII-ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Study Area Boundary

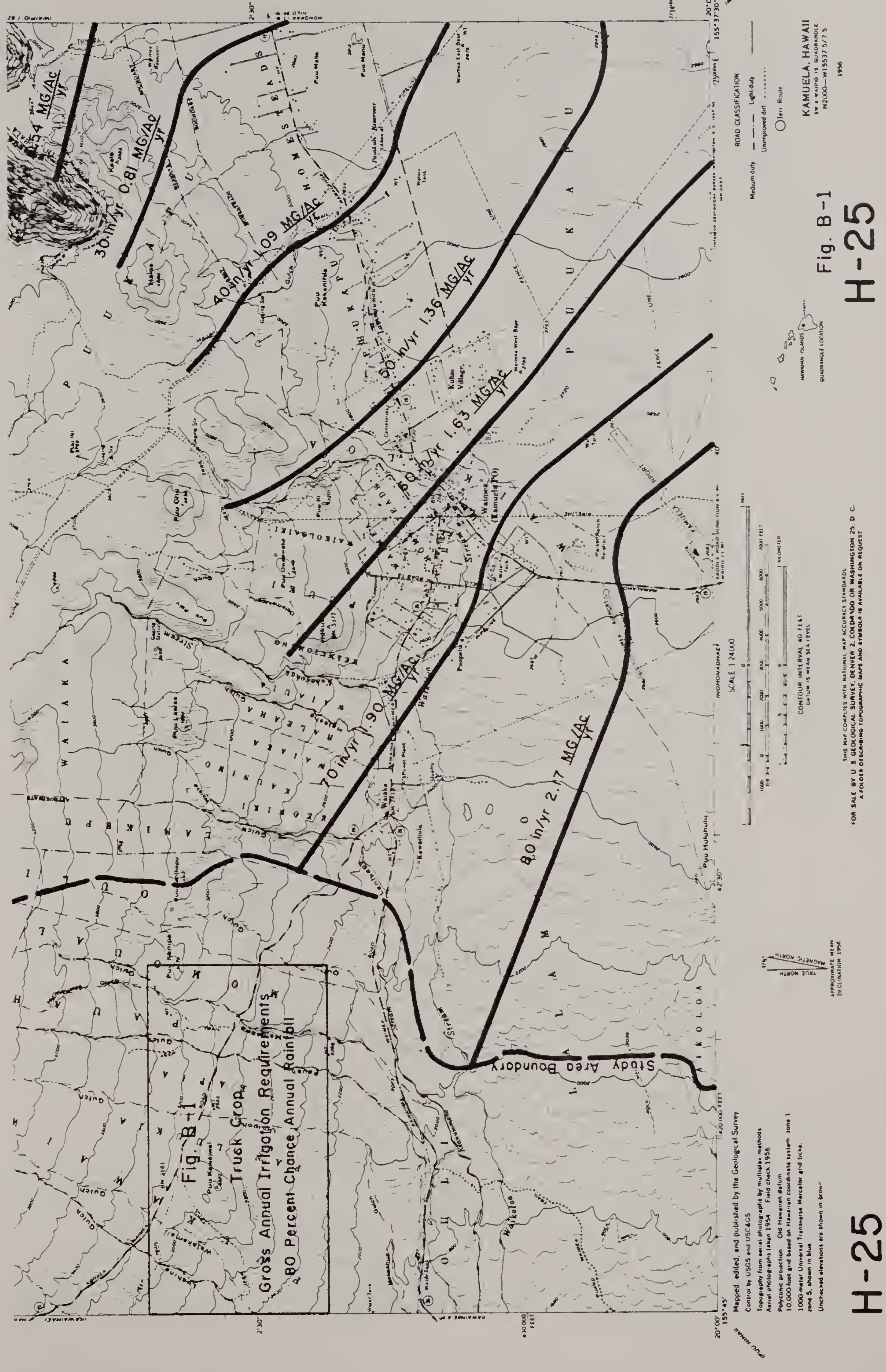
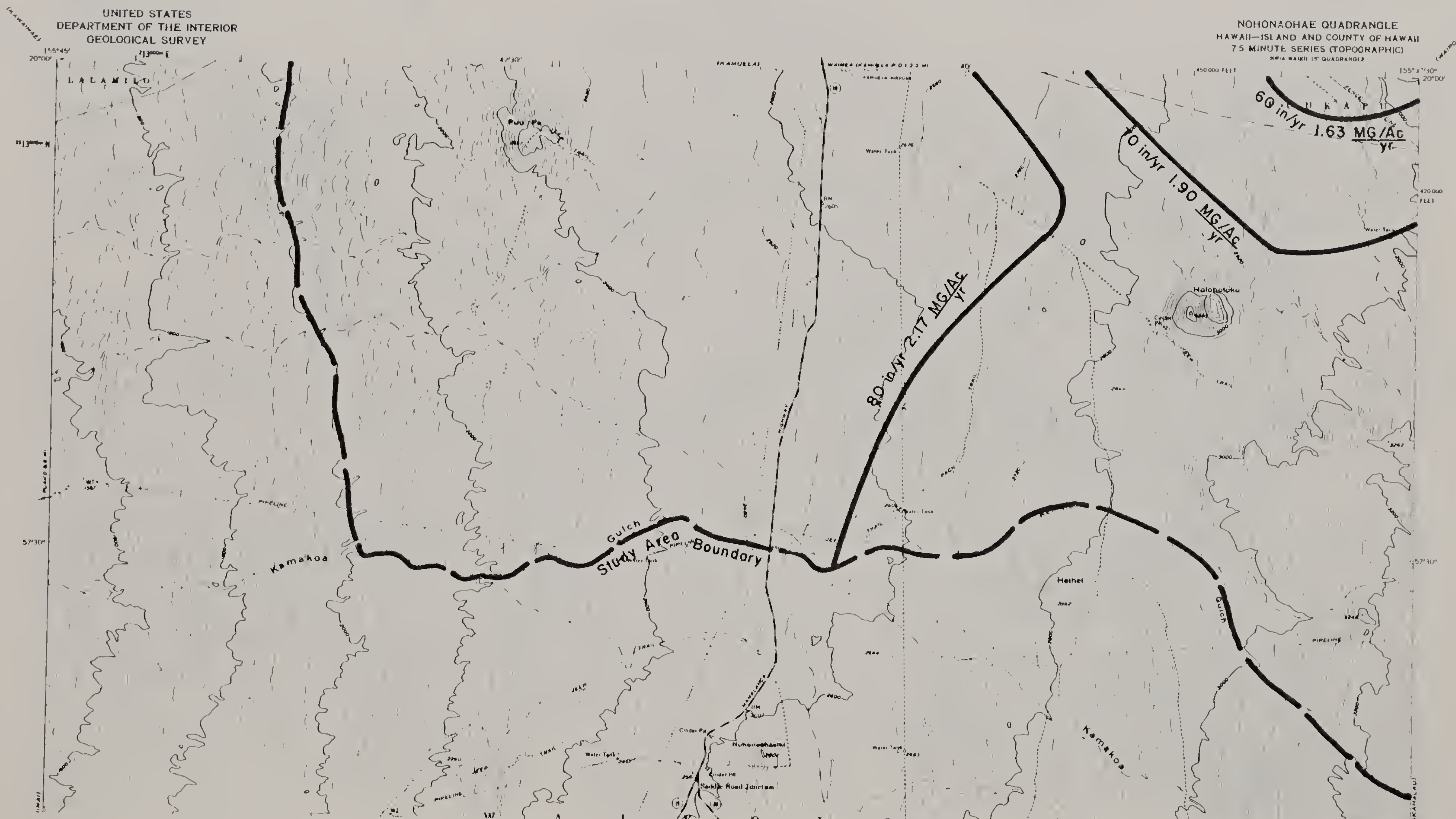


Fig. B-1
Truck Crop
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
NOHONAOHAE QUADRANGLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
60 in/yr 1.63 MG/Ac/yr
70 in/yr 1.90 MG/Ac/yr
80 in/yr 2.17 MG/Ac/yr
Holoholoku
Puu Pa
Kamakoa
Gulch
Study Area Boundary
Heihei
Gulch
Kamakoa
Nohonaohaeiki
Saddle Road Junction
Cinder Pit
Water Tank
PIPELINE
TRAIL
57'30"
155°45'
20°00'

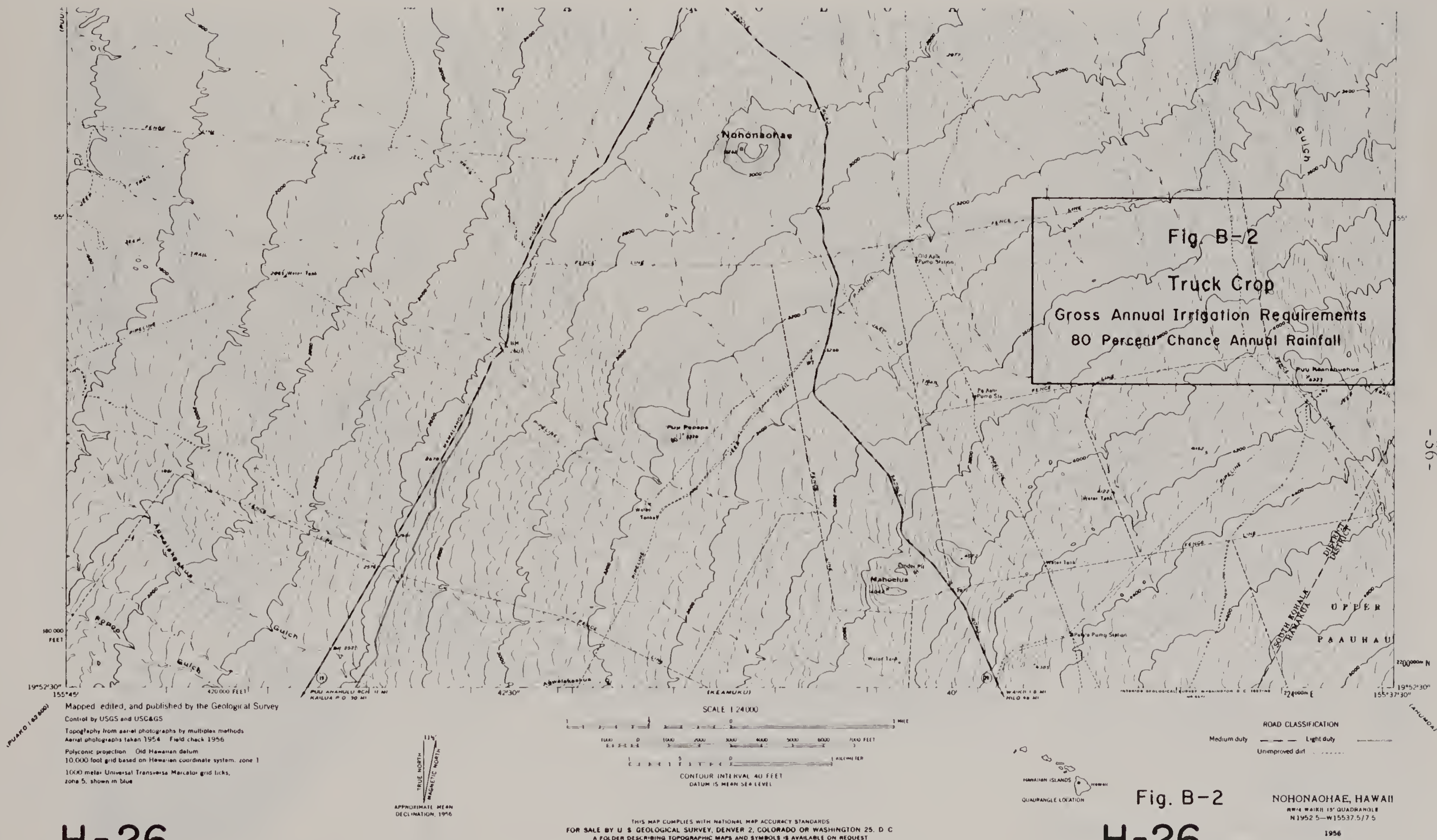


Fig. B-2

H-26

H-26


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
KUKUIHAELE QUADRANGLE
HAWAII–ISLAND AND COUNTY OF HAWAII
7.5' (TOPOGRAPHIC)
Fig. B-3
Truck Crop
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall
PACIFIC OCEAN
WAIPIO BAY
Kukuihaele
Camp 108
HAMAKUA
FOREST RESERVE
20 in/yr 0.54 MG/Ac/yr
30 in/yr 0.81 MG/Ac/yr
15 in/yr 0.41 MG/Ac/yr

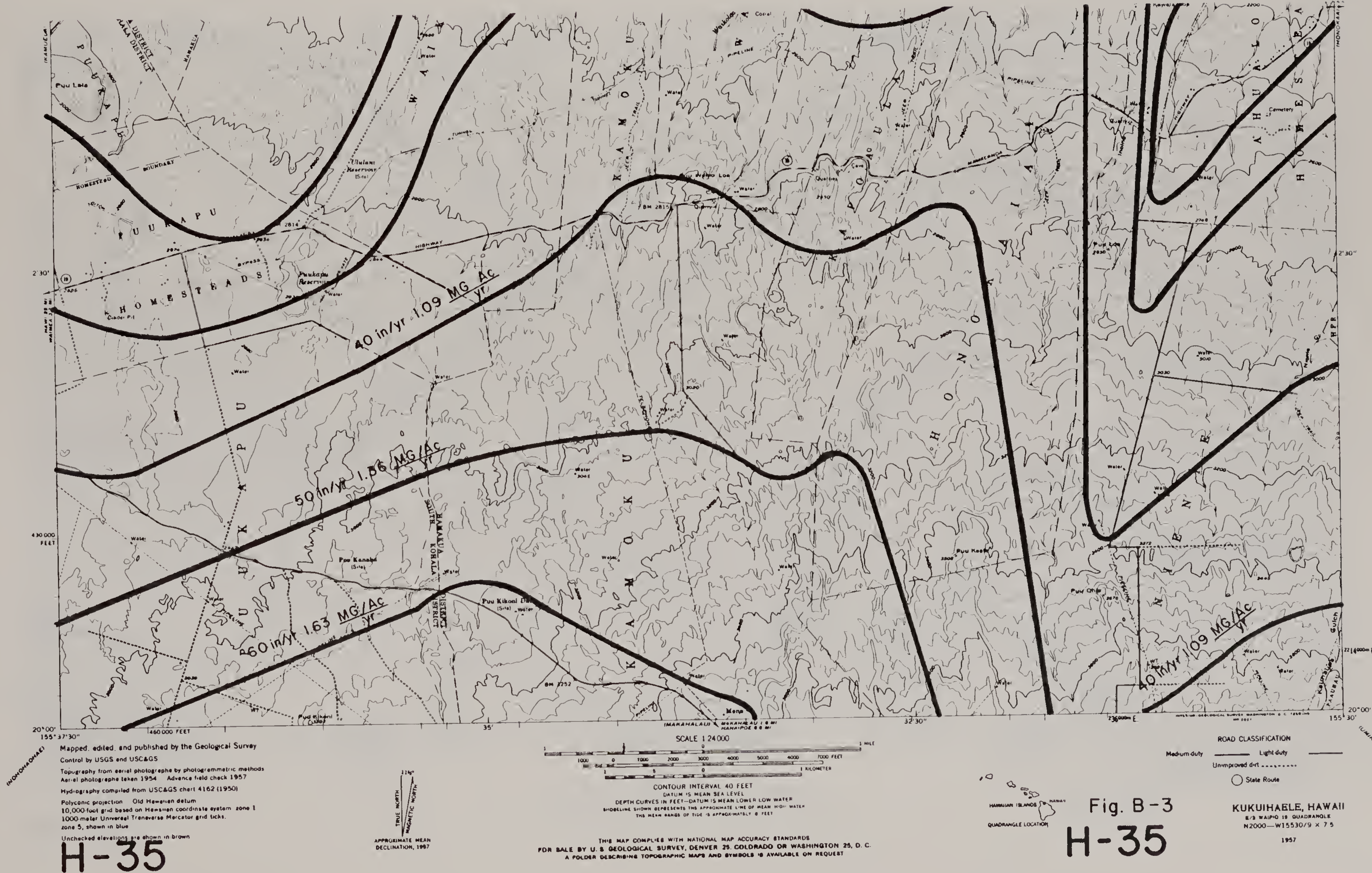
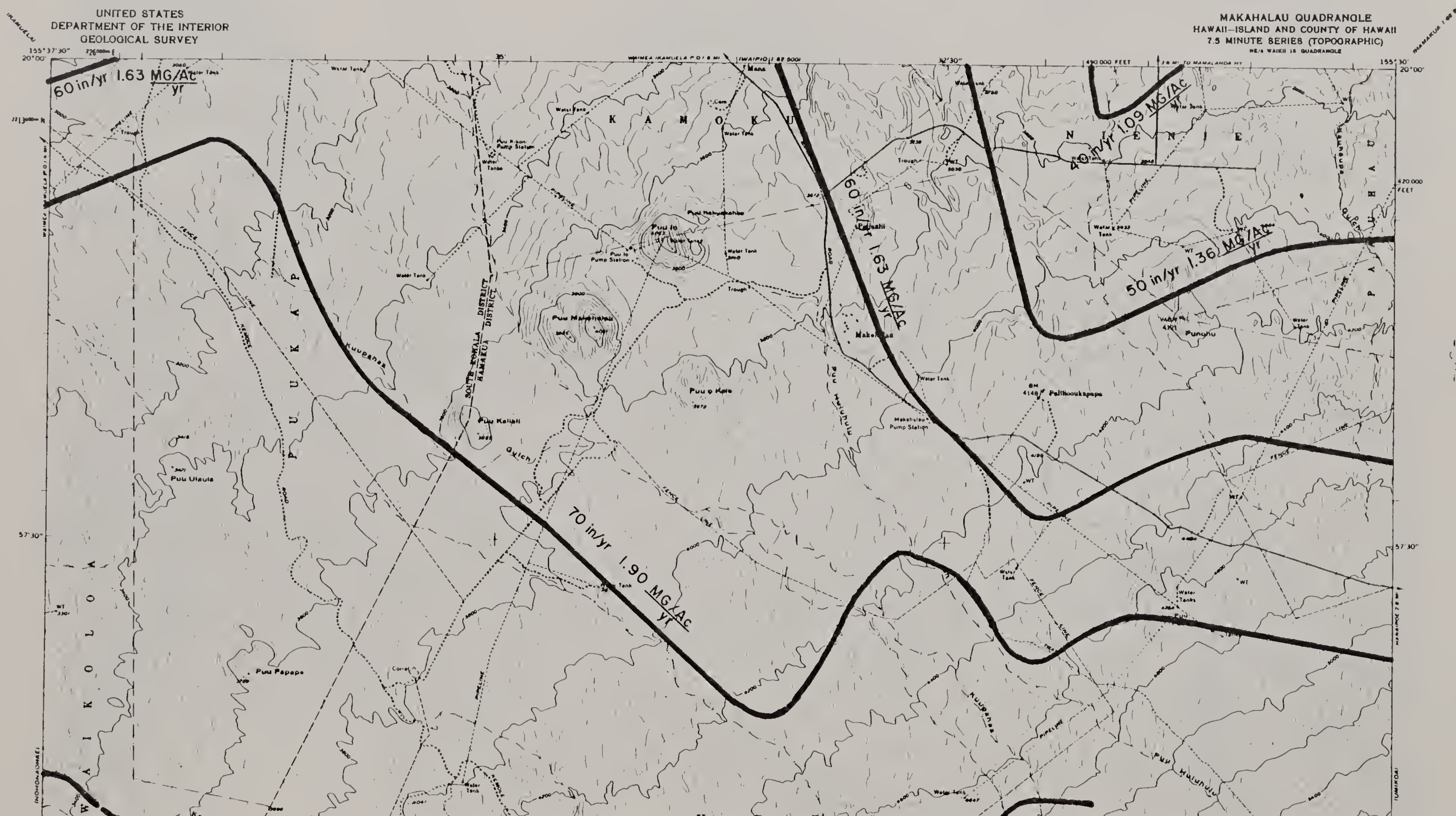

40 in/yr 1.09 MG/Ac/yr
50 in/yr 1.36 MG/Ac/yr
60 in/yr 1.63 MG/Ac/yr
40 in/yr 1.09 MG/Ac/yr
PUUKAPU
HOMESTEADS
WAIKA
KAMOKU
HONOKAIA
AHUALOA HOMESTEADS
NIENIE
PUUKAPU
KAMOKU
Puu Lala
Puukapu Reservoir
Ululani Reservoir (Site)
Puu Kanehe (Site)
Puu Kikoni Dam (Site)
Puu Kawa Loa
Puu Kaala
Puu Ohia
Cemetery
HAMAKUA DISTRICT
SOUTH KOHALA DISTRICT
HIGHWAY
PIPELINE
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1954. Advance field check 1957
Hydrography compiled from USC&GS chart 4162 (1950)
Polyconic projection. Old Hawaiian datum
10,000-foot grid based on Hawaiian coordinate system, zone 1
1000-meter Universal Transverse Mercator grid ticks, zone 5, shown in blue
Unchecked elevations are shown in brown
H-35
TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1957
SCALE 1:24 000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER 25, COLORADO OR WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
HAWAIIAN ISLANDS
QUADRANGLE LOCATION
ROAD CLASSIFICATION
Medium-duty
Light duty
Unimproved dirt
State Route
KUKUIHAELE, HAWAII
N2000—W15530/9 x 7.5
1957

Fig. B-3
H-35


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
MAKAHALAU QUADRANGLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
60 in/yr 1.63 MG/Ac/yr
60 in/yr 1.63 MG/Ac/yr
40 in/yr 1.09 MG/Ac/yr
50 in/yr 1.36 MG/Ac/yr
70 in/yr 1.90 MG/Ac/yr
KAMOKU
NIENIE
PAUAHA
PUUKAPU
WAIKOLOA
Puu Kaliali
Puu Makahalau
Puu o Kale
Puu Ulaula
Puu Papapa
Makahalau Pump Station
Palihooukapapa
SOUTH KOHALA DISTRICT
HAMAKUA DISTRICT

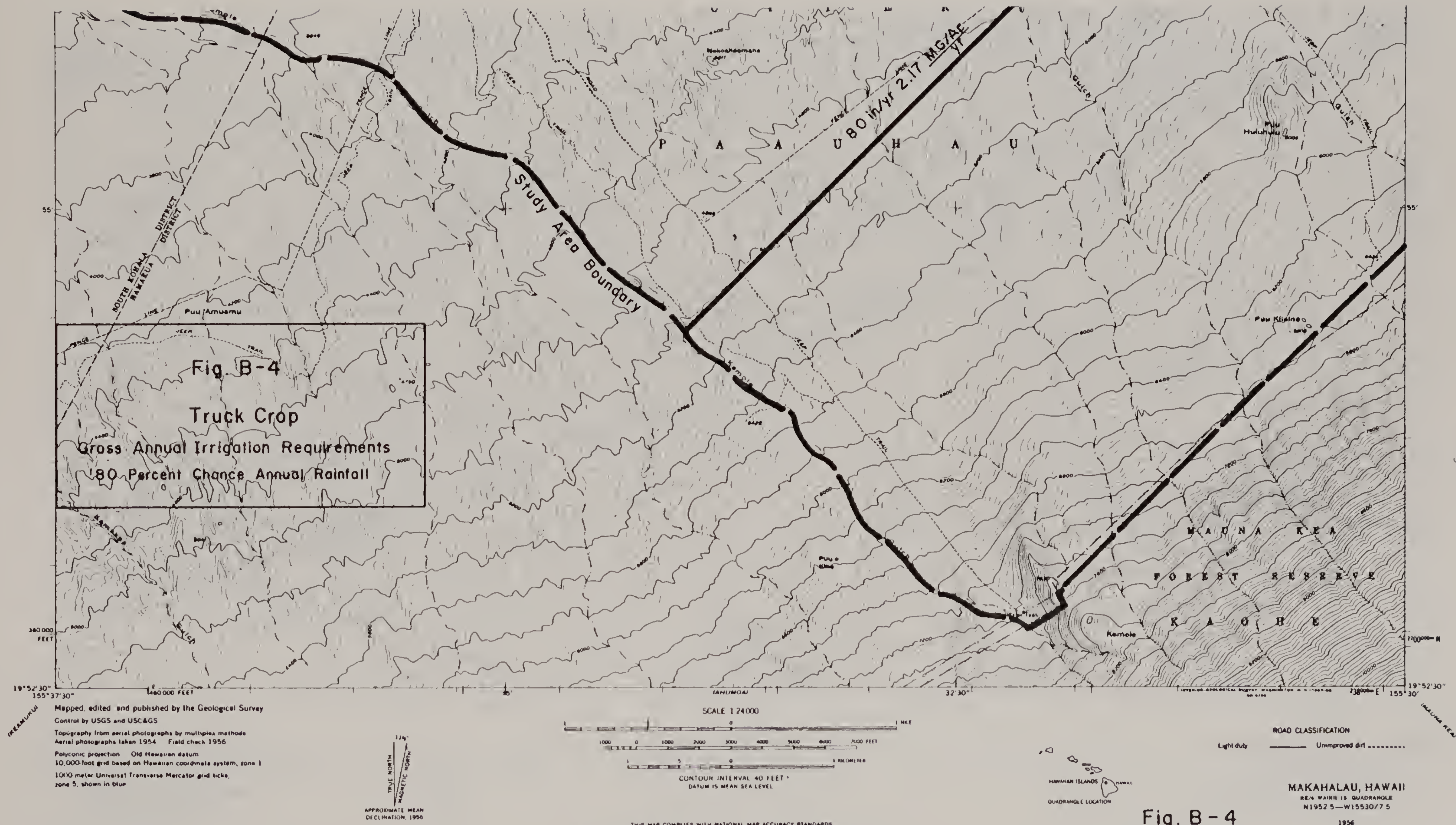


Fig. B-4

H-36

H-36

Fig. B-5

Truck Crop

Gross Annual Irrigation Requirements

80 Percent Chance Annual Rainfall

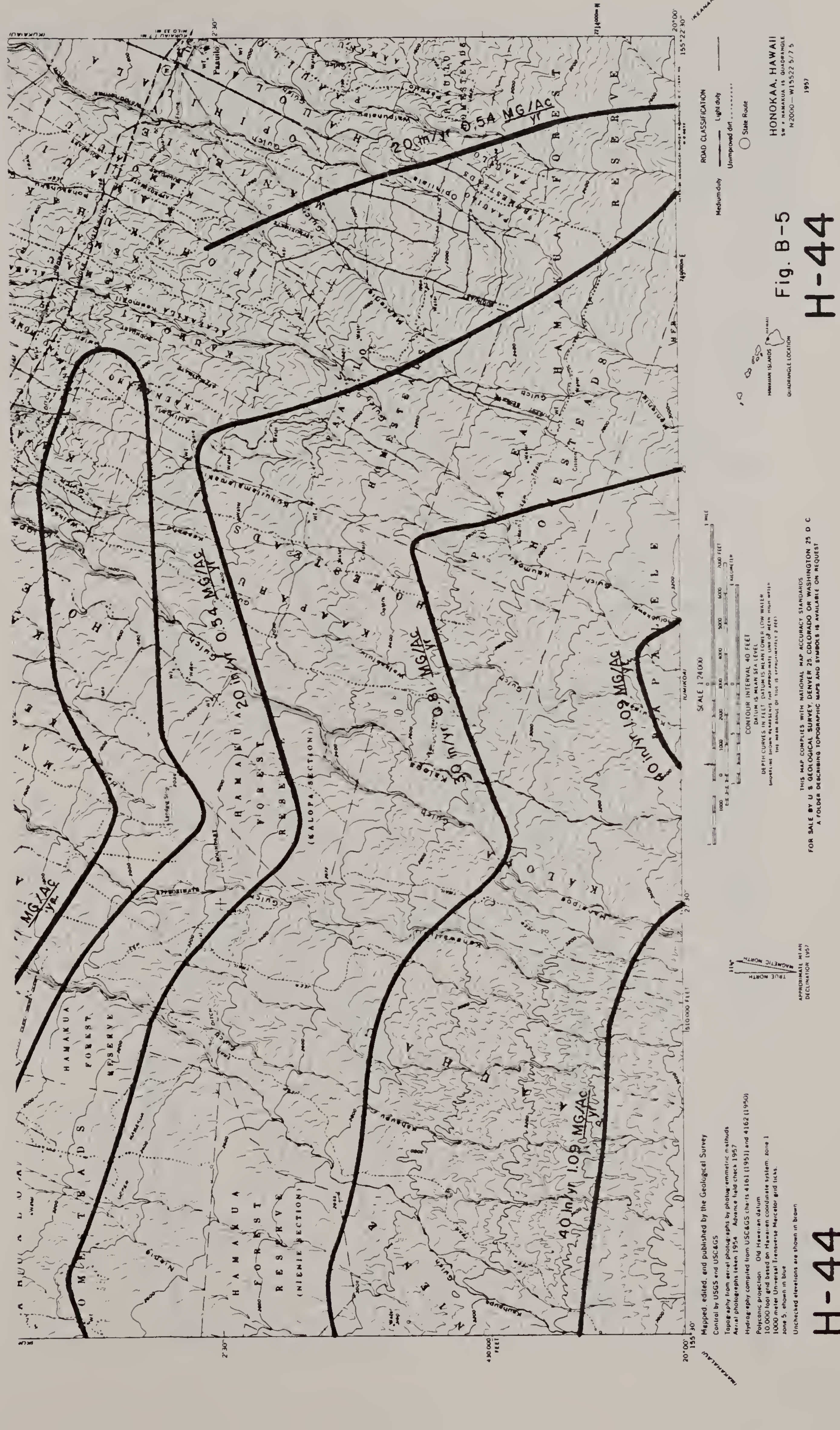
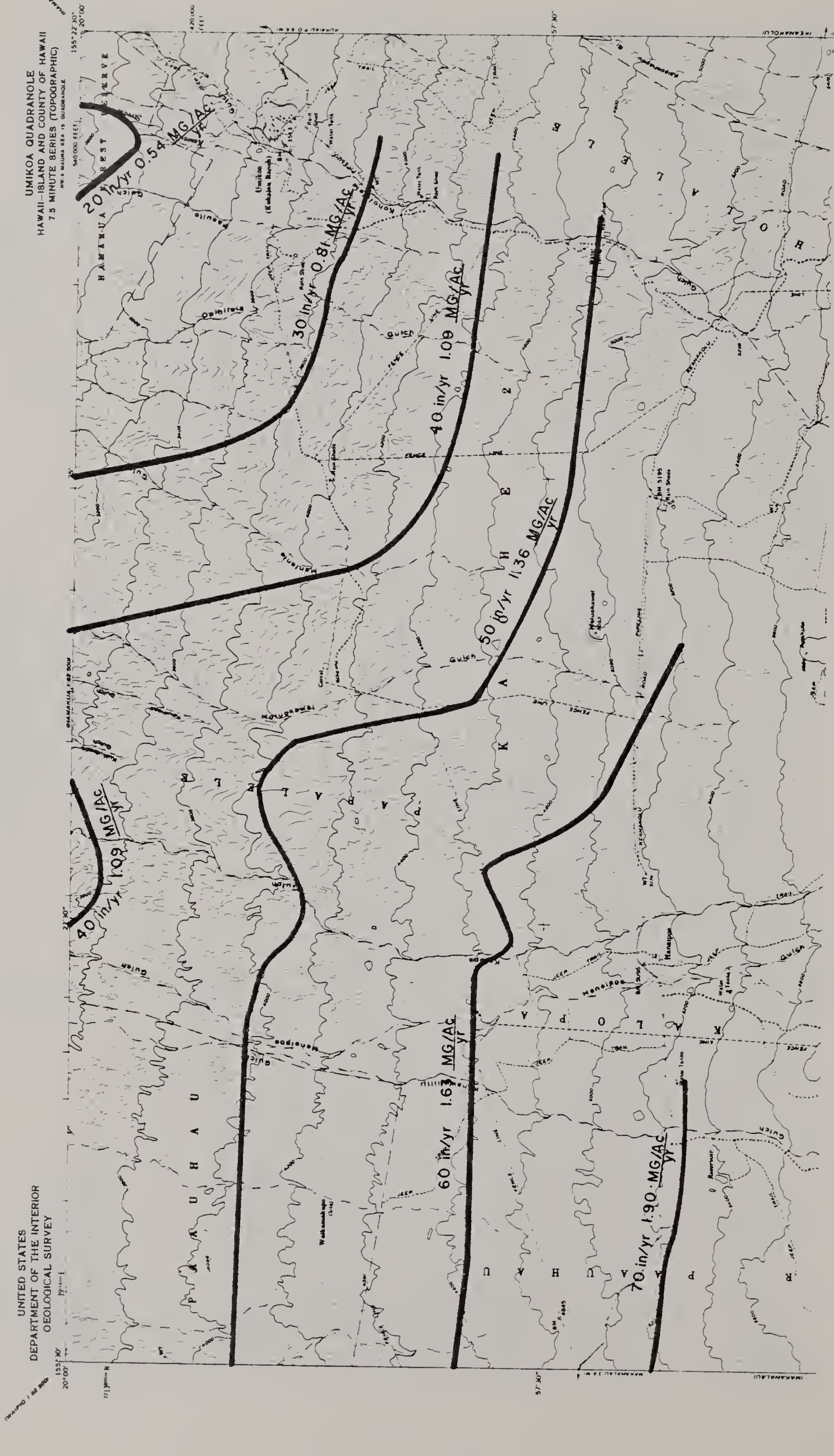

20 in/yr 0.54 MG/Ac/yr
20 in/yr 0.54 MG/Ac/yr
30 in/yr 0.81 MG/Ac/yr
40 in/yr 1.09 MG/Ac/yr
40 in/yr 1.09 MG/Ac/yr
HAMAKUA FOREST RESERVE (NIENIE SECTION)
HAMAKUA FOREST RESERVE (KALOPA SECTION)
ROAD CLASSIFICATION
HONOKAA, HAWAII
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, DENVER 25, COLORADO OR WASHINGTON 25, D C
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
Mapped, edited, and published by the Geological Survey
H-44

Fig. B-5

H-44


UMIKOA QUADRANOLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
20 in/yr 0.54 MG/Ac/yr
30 in/yr 0.81 MG/Ac/yr
40 in/yr 1.09 MG/Ac/yr
50 in/yr 1.36 MG/Ac/yr
40 in/yr 1.09 MG/Ac/yr
60 in/yr 1.63 MG/Ac/yr
70 in/yr 1.90 MG/Ac/yr
Umikoa
Gulch

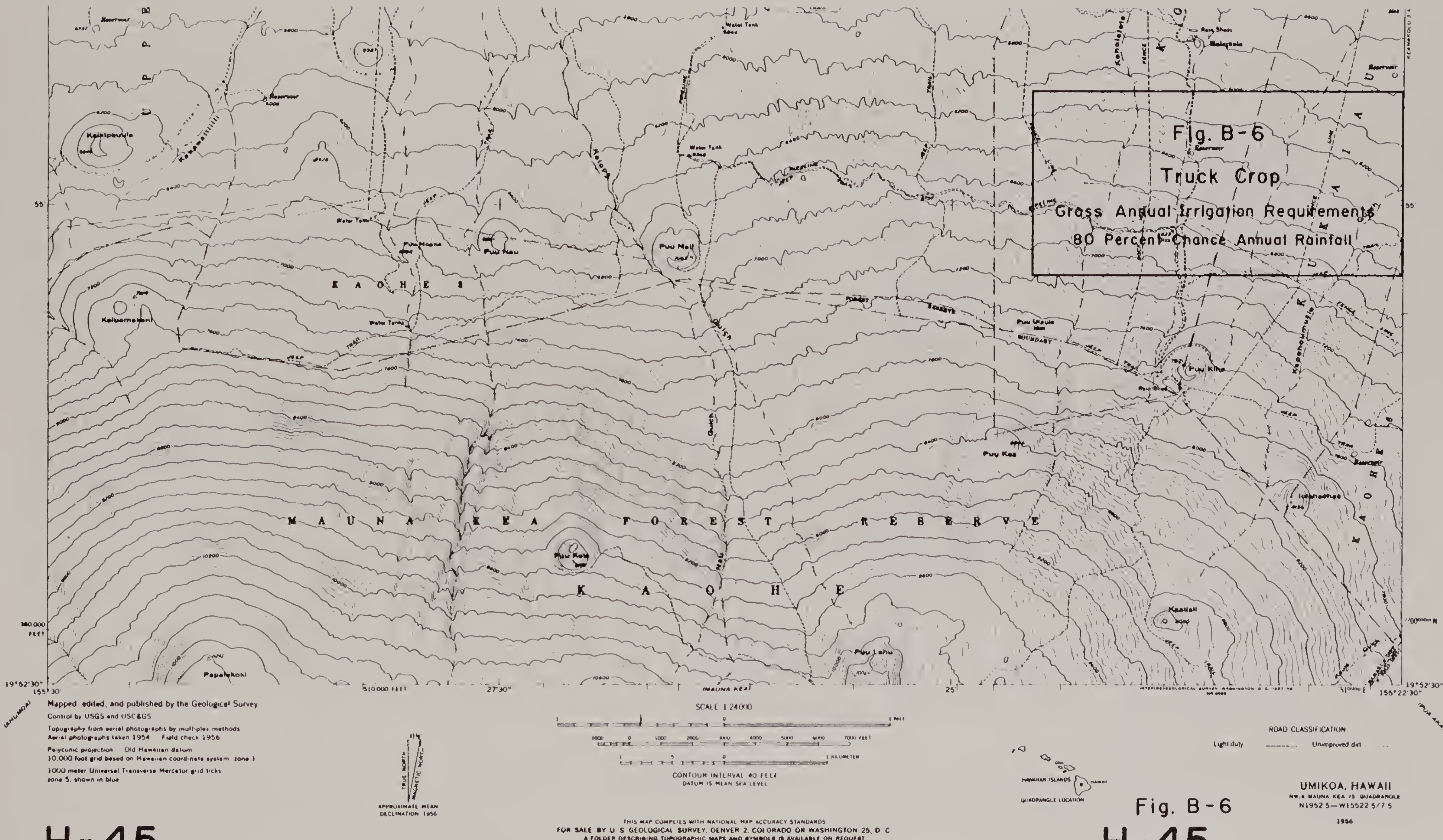


Fig. B-6

H-45

H-45

APPENDIX C

IRRIGATED HAY IRRIGATION WATER REQUIREMENTS

TABLE C-1

Irrigated Hay
Gross Irrigation Requirements - Monthly Distribution
80 Percent Chance Annual Rainfall

Quad.	Annual Irr. Req.		Monthly Gross Irrigation Requirement MG/Ac.											
Sheet	In./Yr.	MG/Ac./Yr.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
H-25	40	1.09	0.02	0.05	.05	.06	0.12	0.16	0.14	0.13	0.15	0.11	0.06	0.03
(Fig. C-1)	60	1.63	0.06	0.08	0.11	0.13	0.18	0.21	0.20	0.17	0.18	0.15	0.10	0.06
	80	2.17	0.07	0.12	0.16	0.18	0.23	0.26	0.25	0.22	0.23	0.19	0.13	0.10
	100	2.72	0.11	0.17	0.22	0.23	0.27	0.31	0.31	0.26	0.26	0.23	0.18	0.15
	120	3.26	0.18	0.26	0.27	0.29	0.32	0.35	0.35	0.30	0.31	0.26	0.21	0.21
H-26	80	2.17	0.07	0.13	0.18	0.20	0.22	0.25	0.25	0.23	0.20	0.19	0.13	0.13
(Fig. C-2)	100	2.72	0.11	0.15	0.19	0.26	0.27	0.31	0.31	0.26	0.28	0.21	0.19	0.16
	120	3.26	0.17	0.21	0.26	0.29	0.31	0.36	0.36	0.32	0.31	0.26	0.20	0.20
H-35	20	0.54	0	0	0	0	0.06	0.11	0.09	0.07	0.12	0.07	0.01	0
(Fig. C-3)	40	1.09	0.03	0.04	0.05	0.06	0.12	0.15	0.15	0.15	0.15	0.12	0.05	0.02
	60	1.63	0.04	0.05	0.08	0.09	0.19	0.23	0.22	0.22	0.23	0.18	0.08	0.02
	80	2.17	0.10	0.11	0.14	0.15	0.23	0.25	0.26	0.26	0.24	0.19	0.13	0.11
H-36	60	1.63	0.07	0.08	0.10	0.13	0.18	0.21	0.19	0.17	0.20	0.13	0.11	0.05
(Fig. C-4)	80	2.17	0.06	0.10	0.15	0.16	0.25	0.28	0.27	0.24	0.22	0.20	0.13	0.11
	100	2.72	0.14	0.17	0.21	0.24	0.26	0.31	0.30	0.25	0.26	0.22	0.17	0.17
H-44	20	0.54	0	0	0	0	0.07	0.14	0.11	0.06	0.11	0.06	0	0
(Fig. C-5)	40	1.09	0.03	0.03	0.04	0.06	0.13	0.17	0.15	0.15	0.16	0.11	0.04	0.02
H-45	40	1.09	0.04	0.03	0.03	0.07	0.13	0.19	0.15	0.15	0.16	0.10	0.03	0.01
(Fig. C-6)	60	1.63	0.10	0.06	0.09	0.11	0.18	0.24	0.19	0.19	0.21	0.14	0.09	0.04
	80	2.17	0.12	0.11	0.13	0.16	0.22	0.29	0.24	0.25	0.25	0.18	0.11	0.10

TABLE C-2

Irrigated Hay
Peak Daily Crop Water and Gross Irrigation Requirements

Quad Sheet	Gross Annual Irrigation Requirements In./Yr.	Gross Annual Irrigation Requirements MG/Ac./Yr.	Peak Daily ET Crop MGD/Ac.	Peak Daily Irrigation Requirements MGD/Ac. Percent Efficiency 50	60	70
H-25	40	1.09	0.0050	0.0100	0.0083	0.0071
(Fig. C-1)	60	1.63	0.0055	0.0110	0.0092	0.0078
	80	2.17	0.0064	0.0128	0.0107	0.0091
	100	2.72	0.0068	0.0227	0.0113	0.0097
	120	3.26	0.0072	0.0144	0.0120	0.0103
H-26	80	2.17	0.0062	0.0124	0.0103	0.0088
(Fig. C-2)	100	2.72	0.0065	0.0130	0.0108	0.0093
	120	3.26	0.0071	0.0142	0.0118	0.0101
H-35	20	0.54	0.0045	0.0090	0.0075	0.0064
(Fig. C-3)	40	1.09	0.0051	0.0102	0.0085	0.0073
	60	1.63	0.0054	0.0108	0.0090	0.0077
	80	2.17	0.0060	0.0120	0.0100	0.0086
H-36	60	1.63	0.0053	0.0106	0.0088	0.0076
(Fig. C-4)	80	2.17	0.0058	0.0116	0.0097	0.0083
	100	2.72	0.0068	0.0136	0.0113	0.0097
H-44	20	0.54	0.0048	0.0096	0.0080	0.0068
(Fig. C-5)	40	1.09	0.0050	0.0100	0.0083	0.0071
H-45	40	1.09	0.0049	0.0098	0.0082	0.0070
(Fig. C-6)	60	1.63	0.0058	0.0116	0.0097	0.0083
	80	2.17	0.0058	0.0116	0.0097	0.0083

Fig. C-1

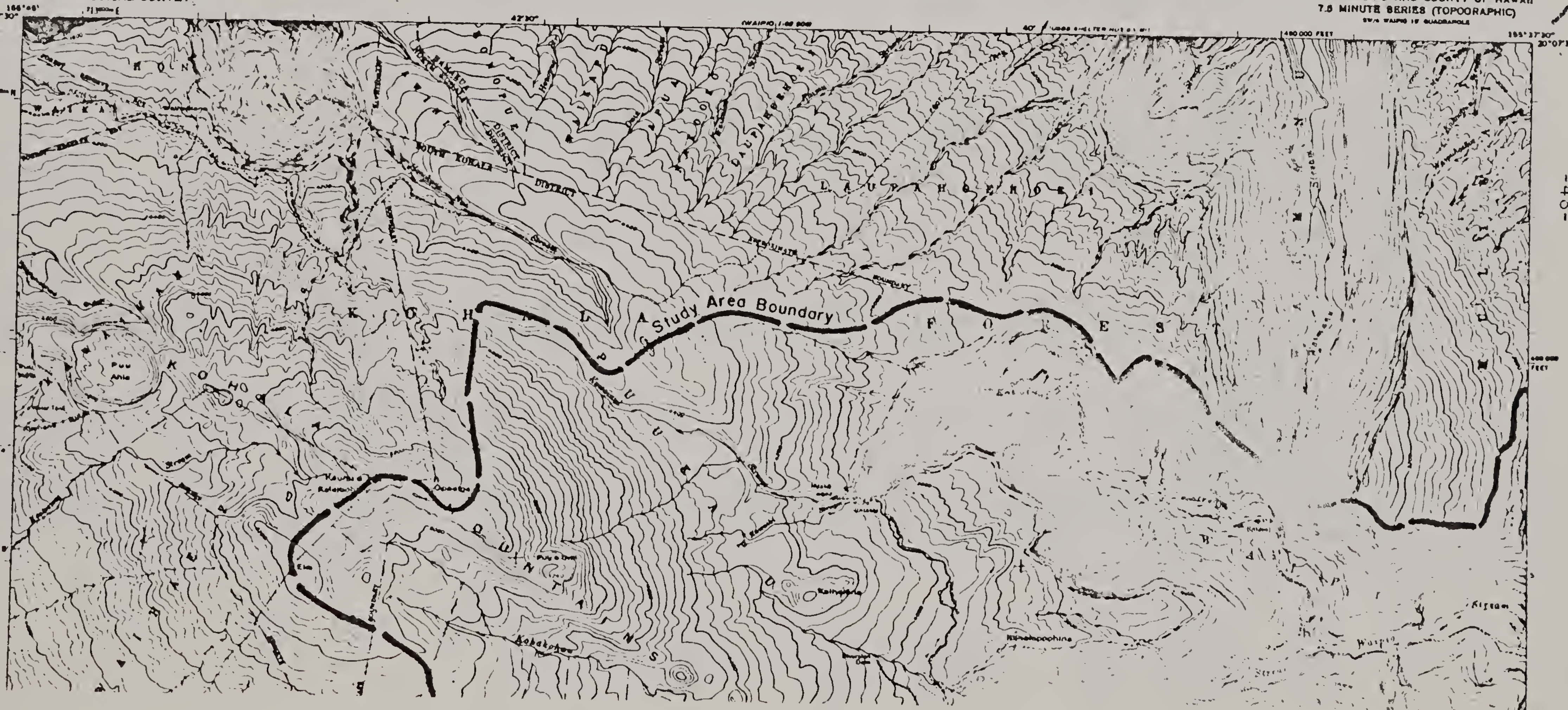

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
KAMUELA QUADRANGLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
Study Area Boundary
SOUTH KOHALA
DISTRICT
Puu Ahia
Kainapaha
Kilohana
Waipio

Fig. C-1

H-25

H-25

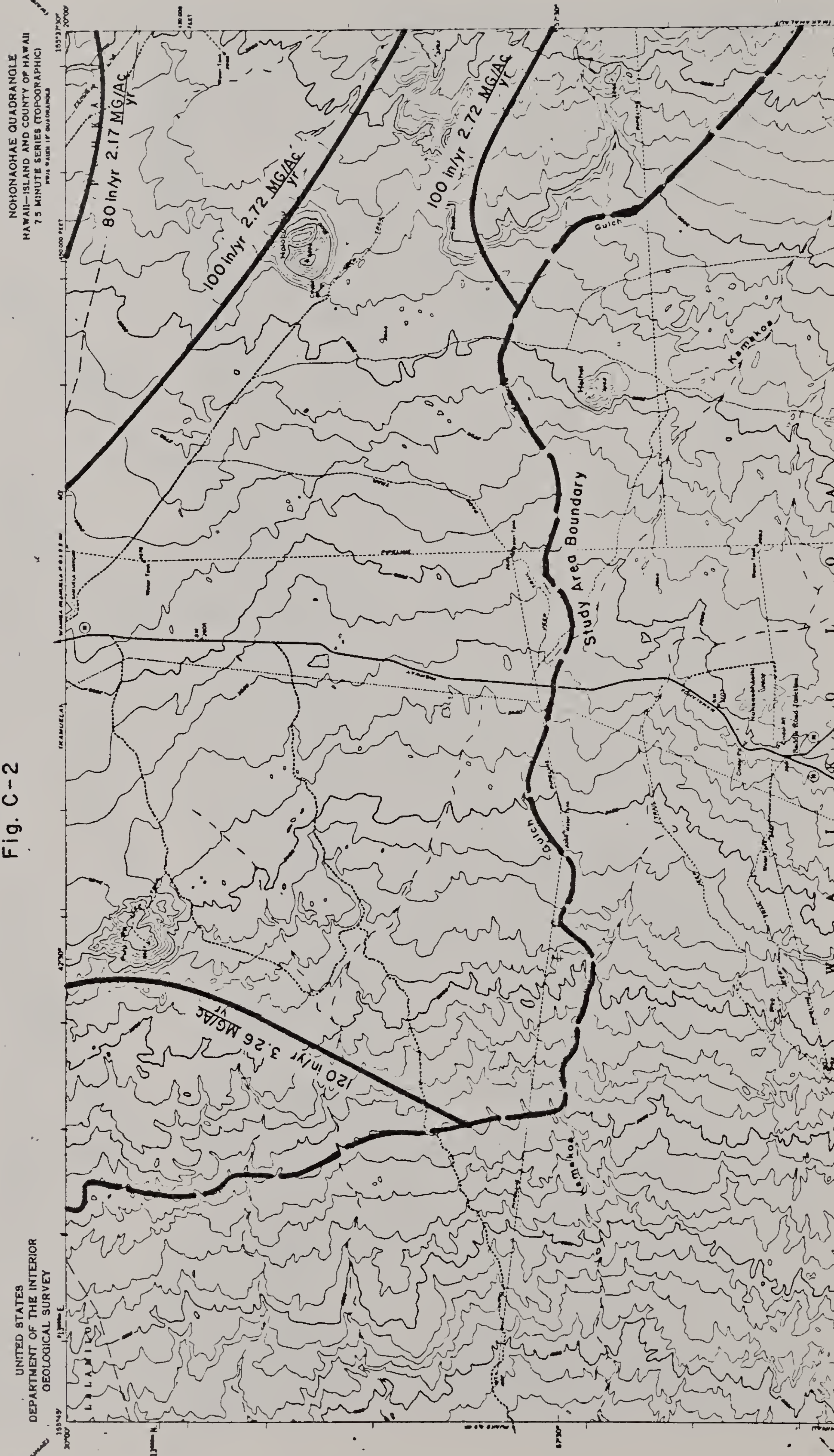

NOHONAOHAE QUADRANGLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
80 in/yr 2.17 MG/Ac yr
100 in/yr 2.72 MG/Ac yr
100 in/yr 2.72 MG/Ac yr
120 in/yr 3.26 MG/Ac yr
Study Area Boundary
Gulch
Gulch
Kamakoa
Kamakoa

Fig. C-2

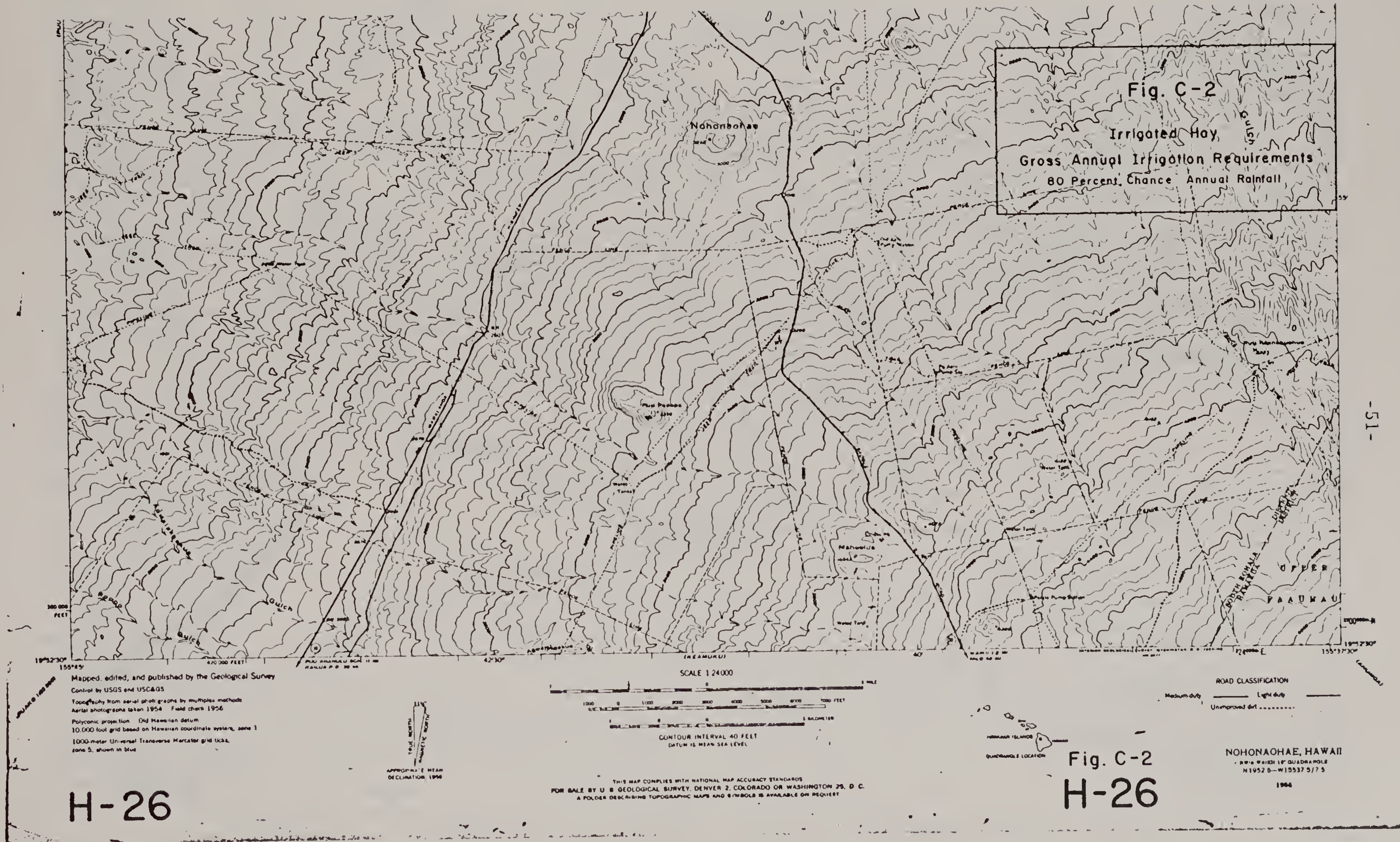


Fig. C-2
Irrigated Hay
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall
Nohonaohae
Gulch
Quich
UPPER
PAAUHAU
Mahoelua
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Polyconic projection. Old Hawaiian datum
10,000 foot grid based on Hawaiian coordinate system, zone 1
1000-meter Universal Transverse Mercator grid ticks, zone 5, shown in blue
APPROXIMATE MEAN DECLINATION 1956
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER 2, COLORADO OR WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
ROAD CLASSIFICATION
Medium duty
Light duty
Unimproved dirt
HAWAIIAN ISLANDS
QUADRANGLE LOCATION
NOHONAOHAE, HAWAII
1956
H-26

Fig. C-2

H-26

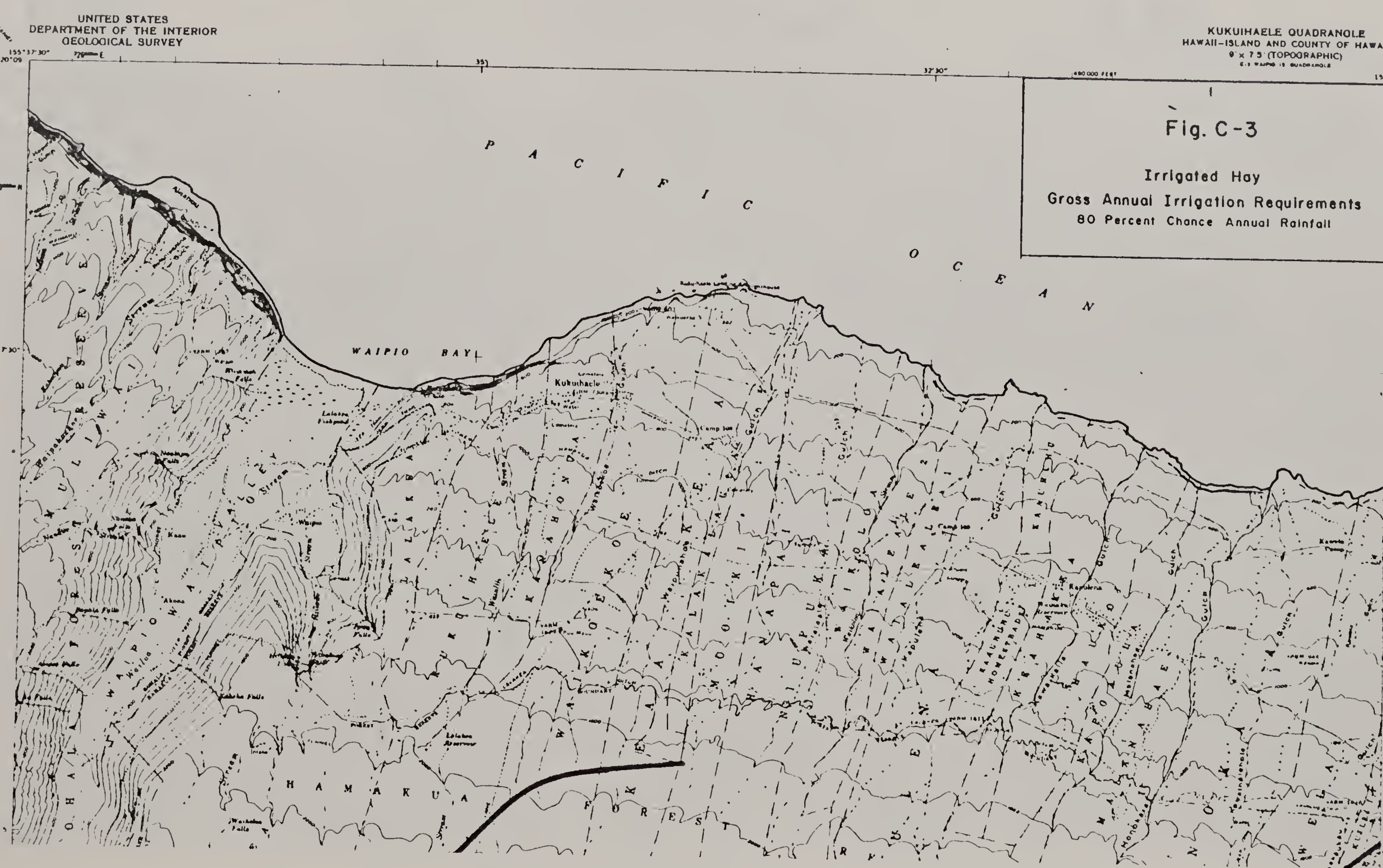


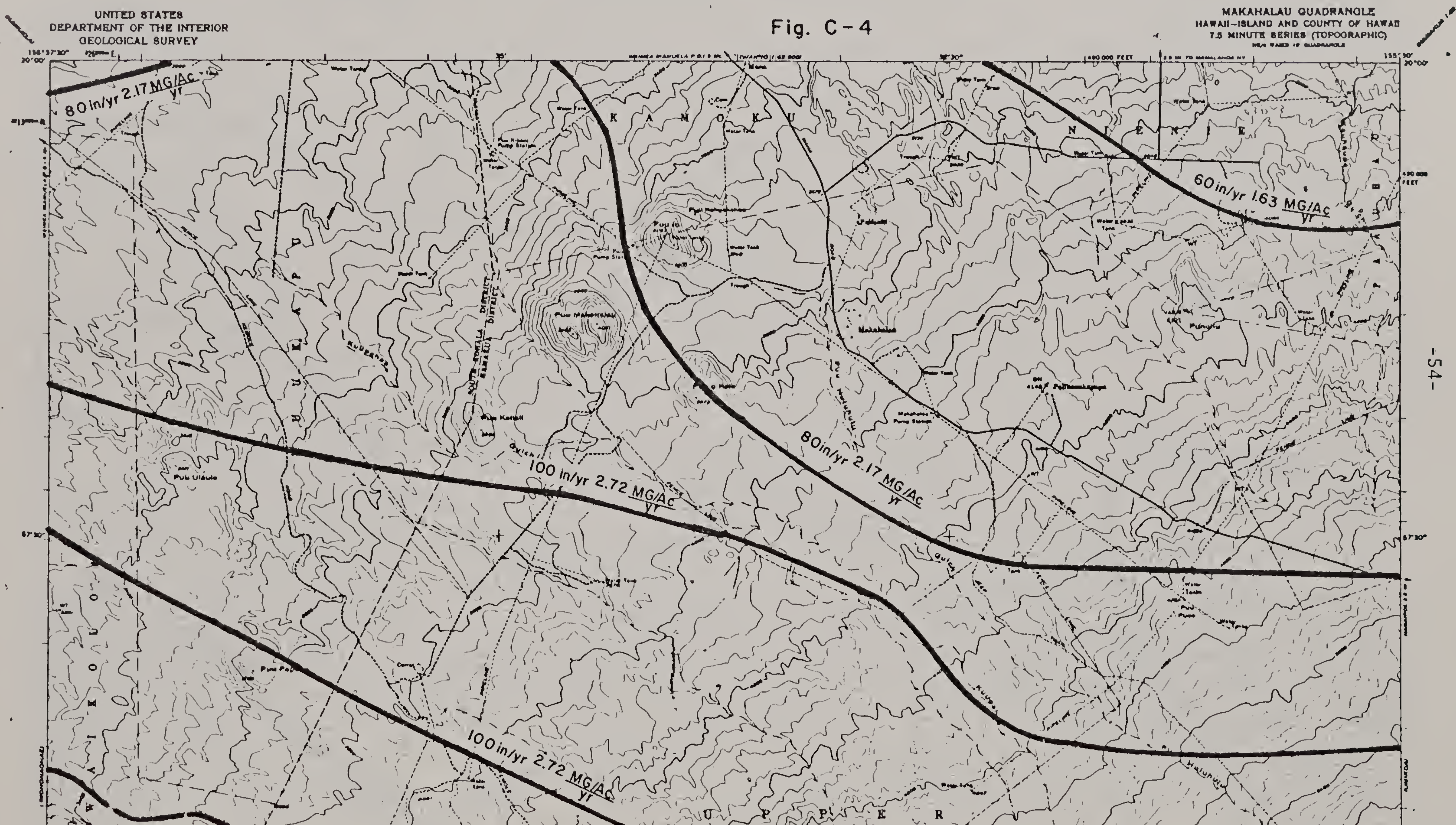
Fig. C-3

Irrigated Hay
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall

Fig. C-3
H-35

H-35

Fig. C-4


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
MAKAHALAU QUADRANGLE
HAWAII-ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
80 in/yr 2.17 MG/AC/yr
60 in/yr 1.63 MG/AC/yr
80 in/yr 2.17 MG/AC/yr
100 in/yr 2.72 MG/AC/yr
100 in/yr 2.72 MG/AC/yr
K A M O K U
N I E N I E
P U U K A P U
U P P E R
SOUTH KOHALA DISTRICT
HAMAKUA DISTRICT
Puu Ulaula
Puu Kaliali
Makahalau
490 000 FEET

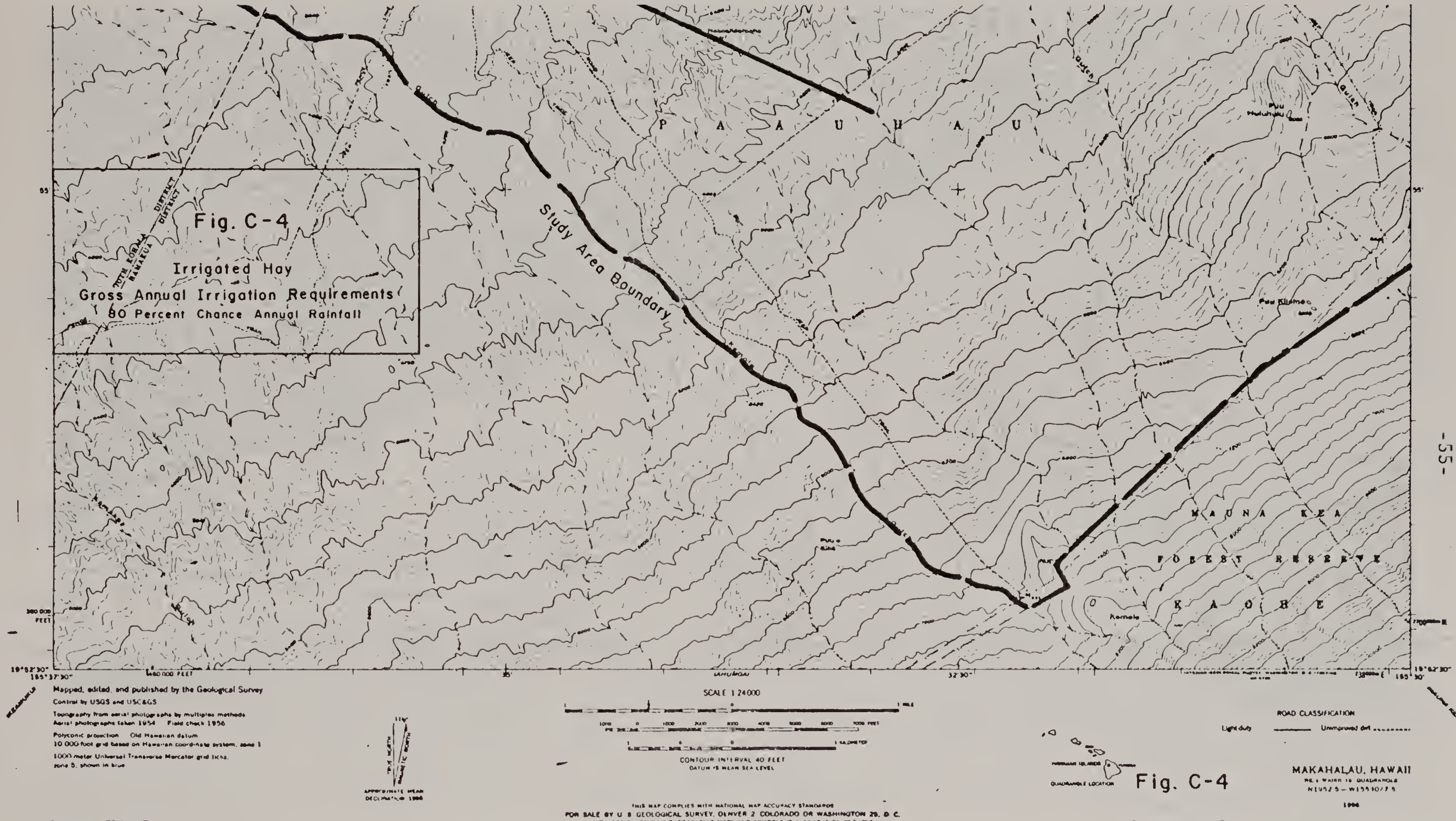


Fig. C-4

H-36

H-36

Fig. C-5

Irrigated Hay

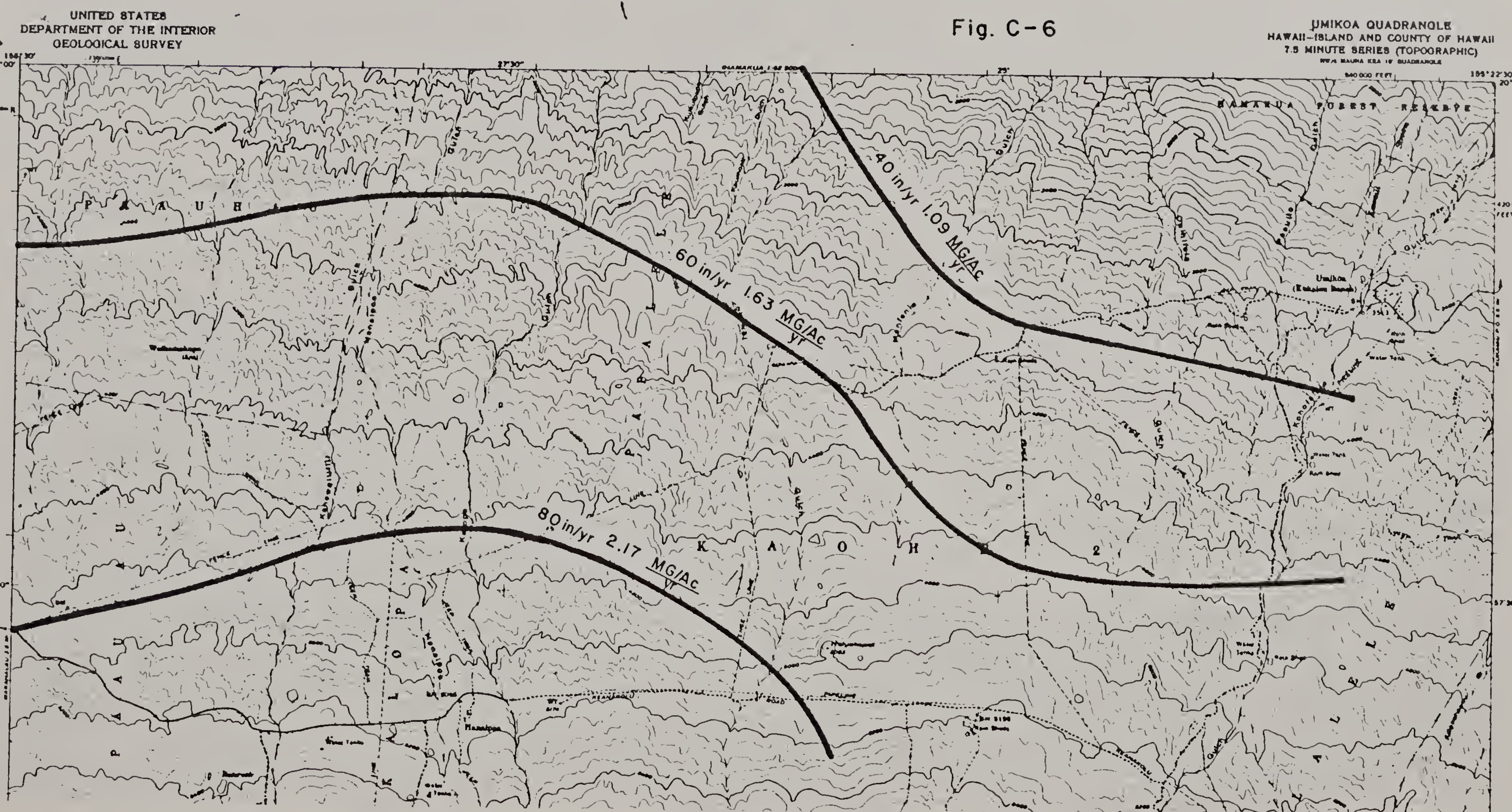
Gross Annual Irrigation Requirements
80 Percent Chance Annual Rainfall

Fig. C-5

H-44

H-44

Fig. C-6


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
UMIKOA QUADRANGLE
HAWAII–ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
40 in/yr 1.09 MG/Ac/yr
60 in/yr 1.63 MG/Ac/yr
80 in/yr 2.17 MG/Ac/yr
HAMAKUA FOREST RESERVE
Umikoa

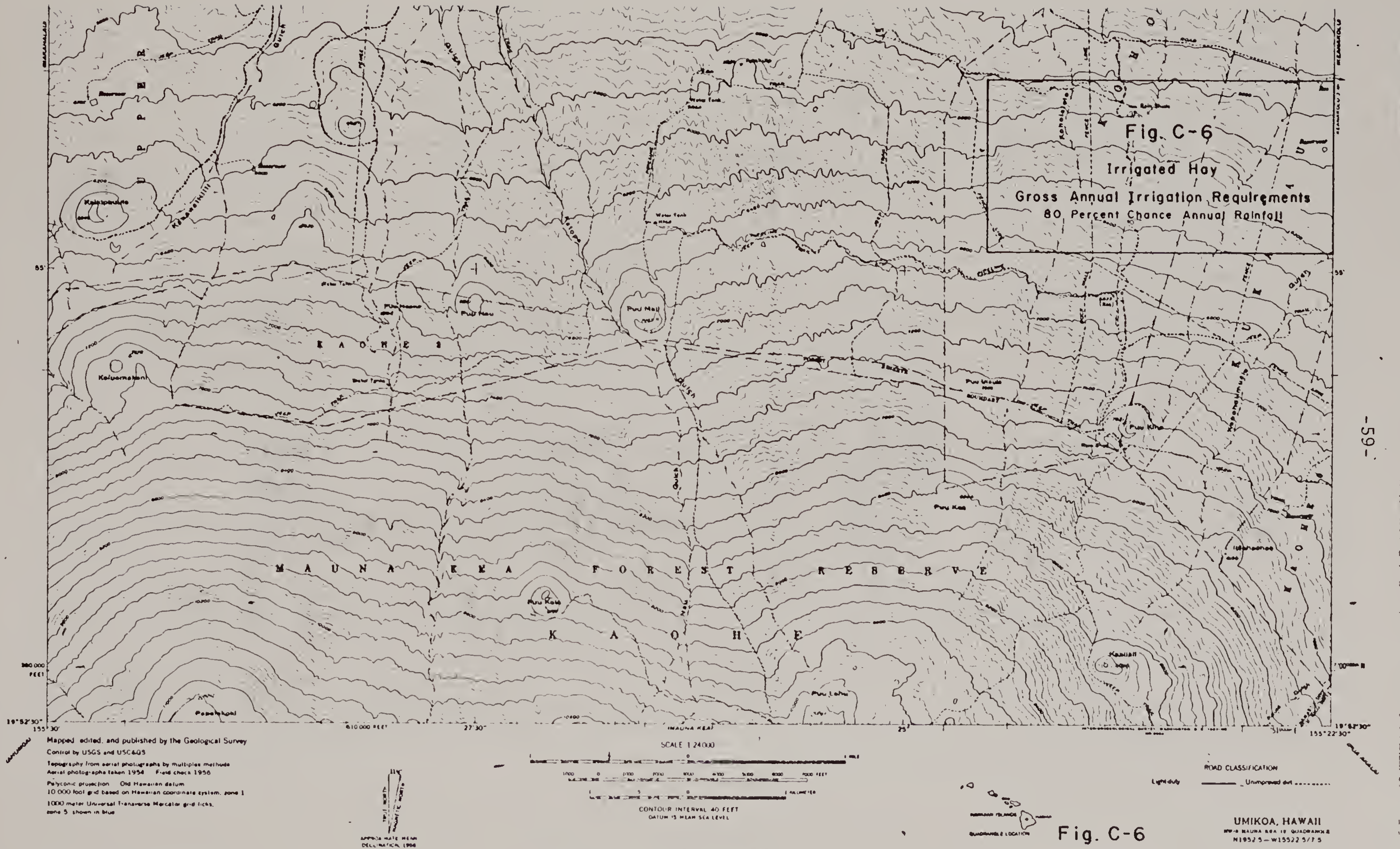


Fig. C-6

H-45

H-45

APPENDIX D

LIVESTOCK WATER REQUIREMENTS

TABLE D-1

Livestock Water Requirements
Monthly Distribution
90 Percent Chance Annual Rainfall

Quad. Sheet	Annual Water Req. Gal./Ac.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
		Monthly Water Requirement Gal./Ac.											
H-25 (Fig. D-1)	1000	80	70	80	80	90	90	90	90	80	90	80	80
	1200	100	90	90	90	100	110	100	100	110	110	100	100
H-26 (Fig. D-2)	1000	80	70	80	80	90	90	90	90	80	90	80	80
H-35 (Fig. D-3)	1000	80	70	80	80	90	90	90	90	80	90	80	80
	1200	100	90	90	90	110	110	110	100	110	100	100	90
	1400	110	100	100	110	130	130	130	120	130	130	110	100
	1600	130	120	120	120	140	150	140	140	150	150	120	120
	1800	140	130	130	120	160	180	170	160	170	170	140	130
	2000	160	140	140	130	180	200	190	170	200	190	160	140
H-36 (Fig. D-4)	1000	80	70	80	80	90	90	90	90	80	90	80	80
	1200	100	90	90	90	110	110	110	100	110	100	100	90
H-44 (Fig. D-5)	1400	110	100	100	110	130	130	130	120	130	130	110	100
	1600	130	110	120	120	150	150	150	140	150	150	120	110
	1800	140	130	130	120	160	180	170	160	170	170	140	130
	2000	160	140	140	130	180	200	190	180	200	190	150	140
H-45 (Fig. D-6)	1000	80	70	80	80	90	90	90	90	80	90	80	80
	1200	100	90	90	90	110	110	110	100	110	100	100	90
	1400	110	100	100	110	130	130	130	120	130	130	110	100
	1600	130	110	120	120	150	150	150	140	150	150	120	110
	1800	140	130	120	130	160	180	170	160	170	170	140	130
	2000	150	140	130	140	190	200	200	180	190	190	150	140
H-53 (Fig. D-7)	1400	120	100	50	60	120	170	150	130	180	150	100	70
	1600	130	110	90	110	150	170	150	140	180	150	120	100
	1800	140	110	90	110	170	180	190	170	180	190	140	110
	2000	170	130	140	150	190	210	200	150	190	190	150	130

TABLE D-2

Livestock Water Requirements
Peak Daily Water Requirements

Quad. Sheet	Annual Water Req. Gal./Ac.	Peak Daily Water Req. Gal./Ac./Day
H-25	1000	3
(Fig. D-1)	1200	4
H-26	1000	2
(Fig. D-2)		
H-35	1000	3
(Fig. D-3)	1200	4
	1400	4
	1600	5
	1800	6
	2000	7
H-36	1000	3
(Fig. D-4)	1200	4
H-44	1400	4
(Fig. D-5)	1600	5
	1800	6
	2000	7
H-45	1000	3
(Fig. D-6)	1200	4
	1400	4
	1600	5
	1800	7
	2000	8
H-53	1400	6
(Fig. D-7)	1600	6
	1800	7
	2000	7

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Fig. D-1

KAMUELA QUADRANGLE
HAWAII–ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)

Fig. D-1

H-25

H-25

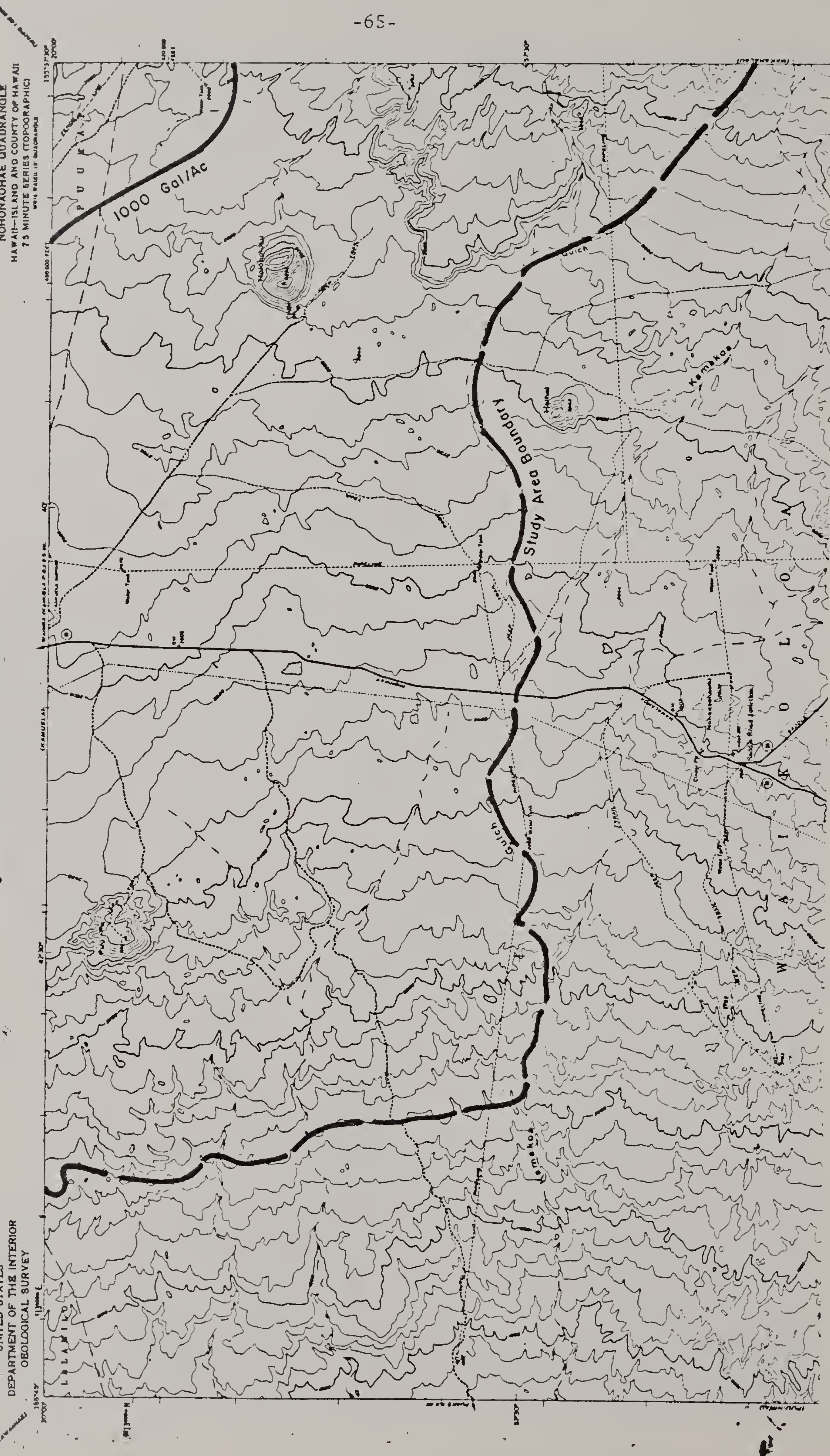

NOHONAOHAE QUADRANGLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
1000 Gal/Ac
Study Area Boundary
Gulch
Kamakoa

Fig. D-2

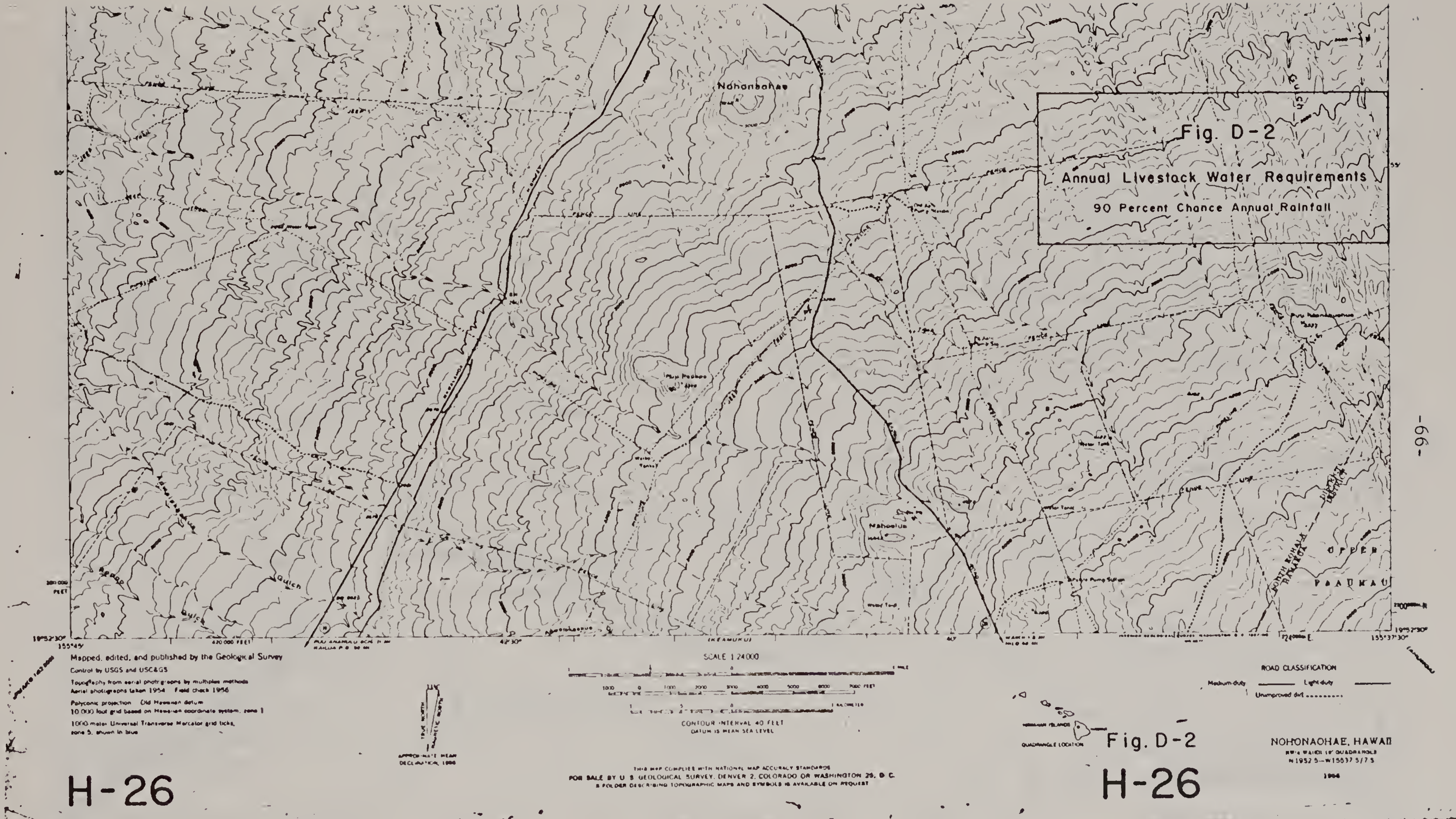


Fig. D-2
Annual Livestock Water Requirements
90 Percent Chance Annual Rainfall
Nohonbohae
Nahoolua
OPPER
PAAUHAU
Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by multiplex methods
Aerial photographs taken 1954. Field check 1956
Polyconic projection. Old Hawaiian datum
10,000 foot grid based on Hawaiian coordinate system, zone 1
1000-meter Universal Transverse Mercator grid ticks, zone 5, shown in blue
SCALE 1:24000
CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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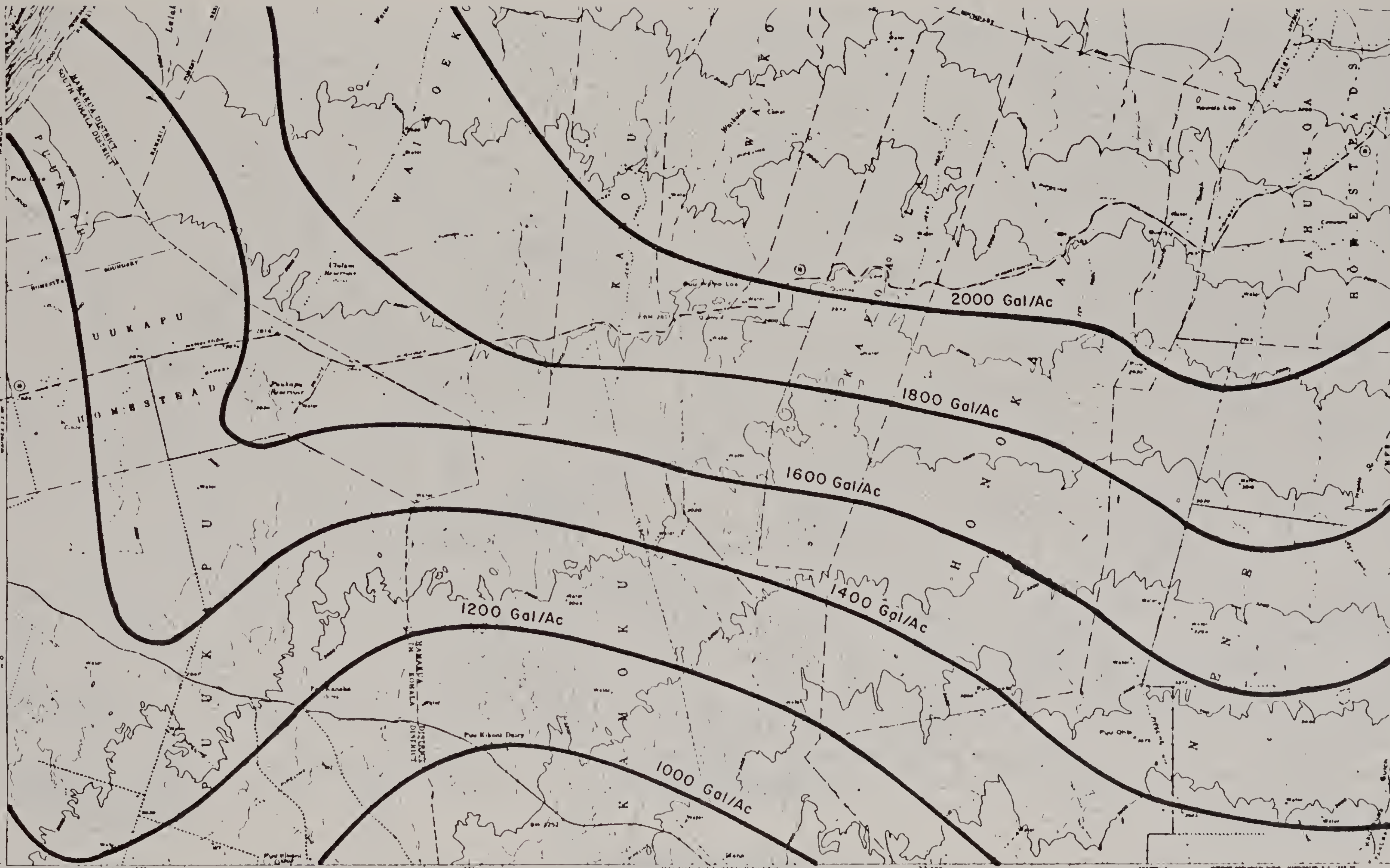
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
ROAD CLASSIFICATION
Medium-duty
Light-duty
Unimproved dirt
QUADRANGLE LOCATION
NOHONAOHAE, HAWAII
1956
H-26
Fig. D-2
H-26

Fig. D-3

Annual Livestock Water Requirements

90 Percent Chance Annual Rainfall



Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by photogrammetric methods
Aerial photographs taken 1954. Advance field check 1957
Hydrography compiled from USC&GS chart 4162 (1950)
Polyconic projection. Old Hawaiian datum
10,000-foot grid based on Hawaiian coordinate system, zone 1
1000-meter Universal Transverse Mercator grid ticks, zone 5, shown in blue
Unchecked elevations are shown in brown

H-35

APPROXIMATE MEAN DECLINATION, 1957

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL
DEPTH CURVES IN FEET—DATUM IS MEAN LOWER LOW WATER

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
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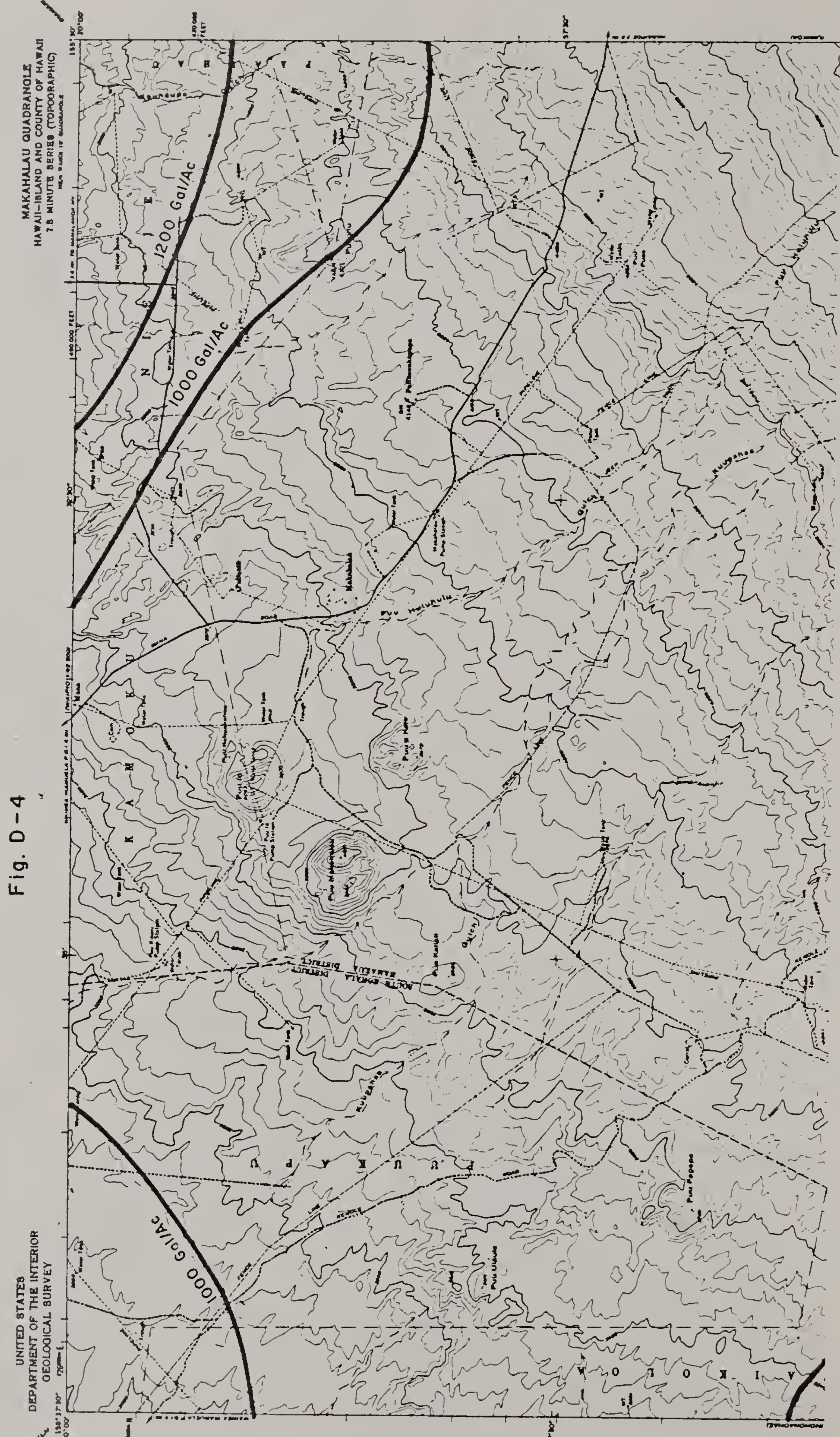
QUADRANGLE LOCATION

Fig. D-3

H-35

ROAD CLASSIFICATION
Medium duty — Light duty
Unimproved dirt
State Route

KUKUIHAELE, HAWAII
N2000—W15530/7.5
1957


MAKAHALAU QUADRANGLE
HAWAII-ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)
UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
1200 Gal/Ac
1000 Gal/Ac
1000 Gal/Ac
SOUTH KOHALA DISTRICT
HAMAKUA DISTRICT
Fig. D-4

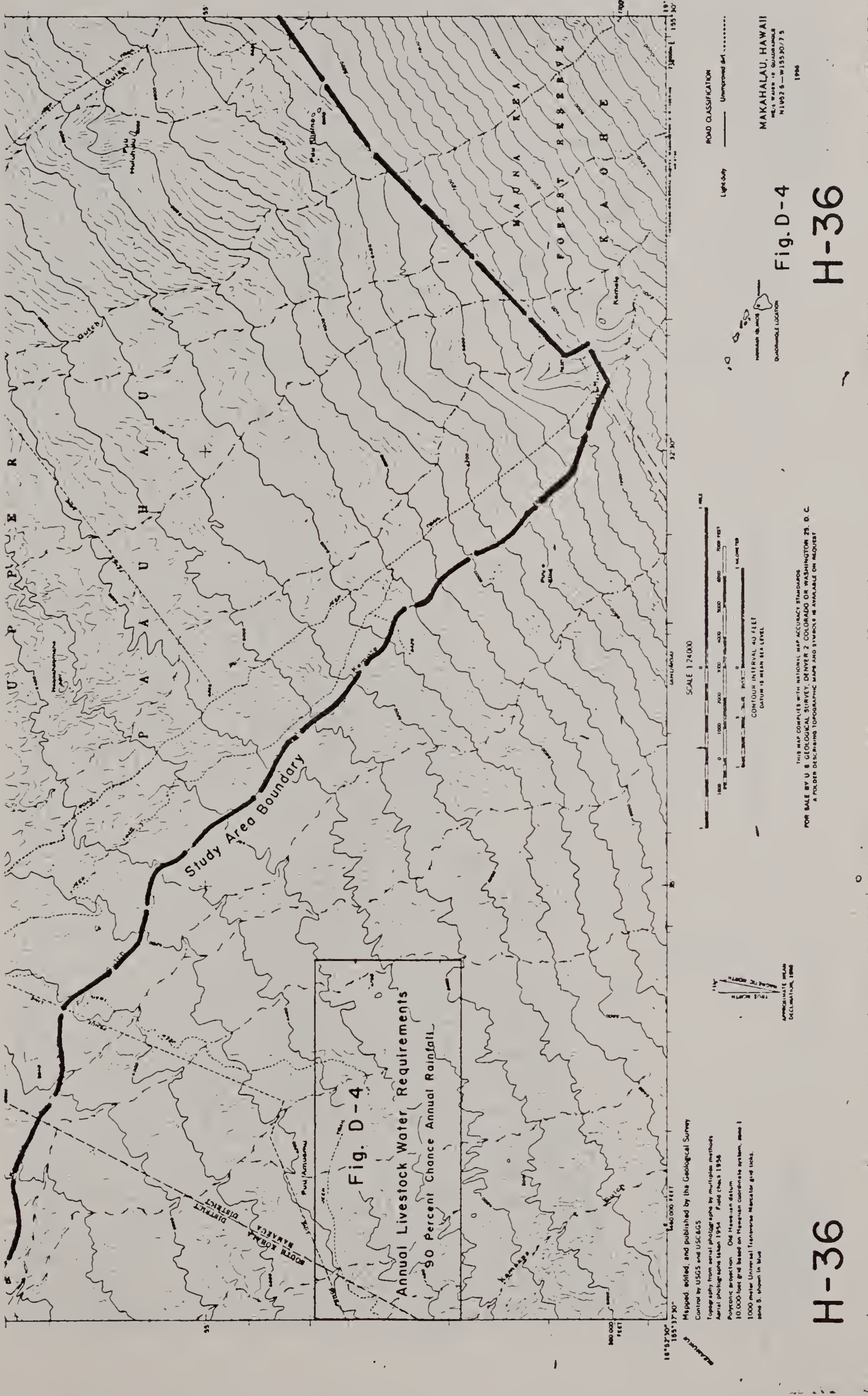


Fig. D-4
Annual Livestock Water Requirements
90 Percent Chance Annual Rainfall
Study Area Boundary
MAKAHALAU, HAWAII
Fig. D-4
H-36
H-36

Fig. D-5

Fig. D-5

Annual Livestock Water Requirements

90 Percent Chance Annual Rainfall

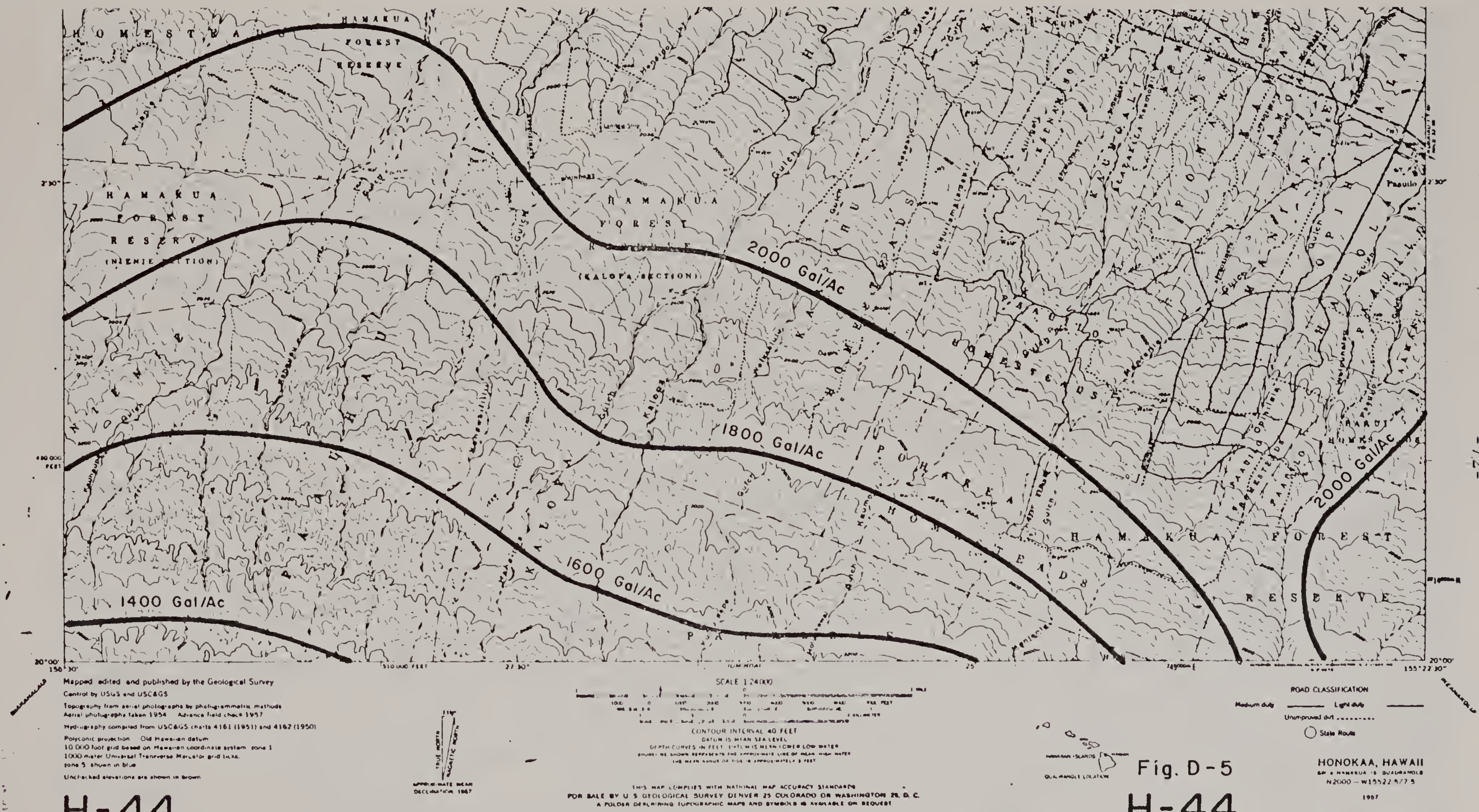


Fig. D-5

H-44

H-44

UMIKOA QUADRANGLE
HAWAII–ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)

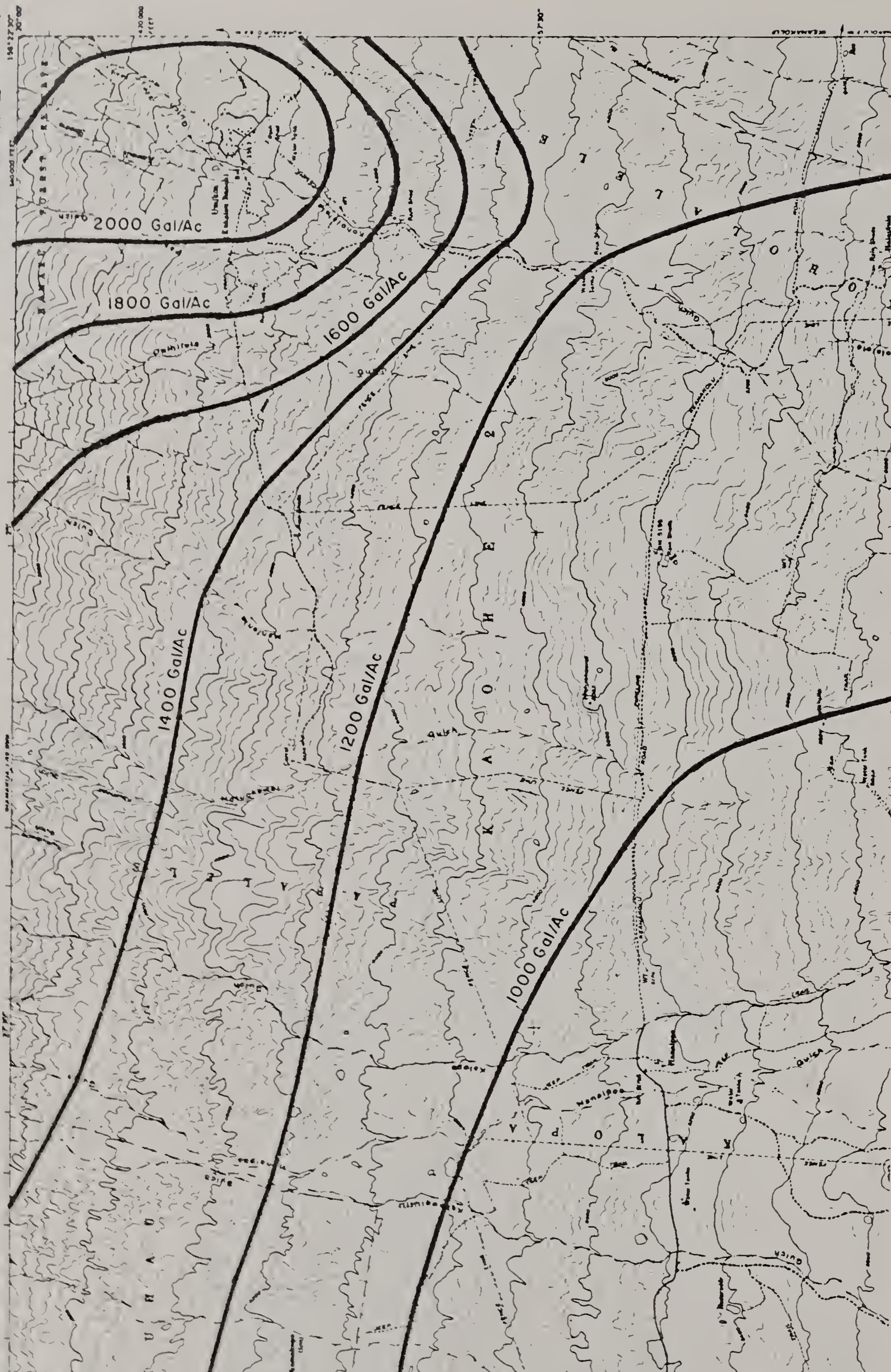
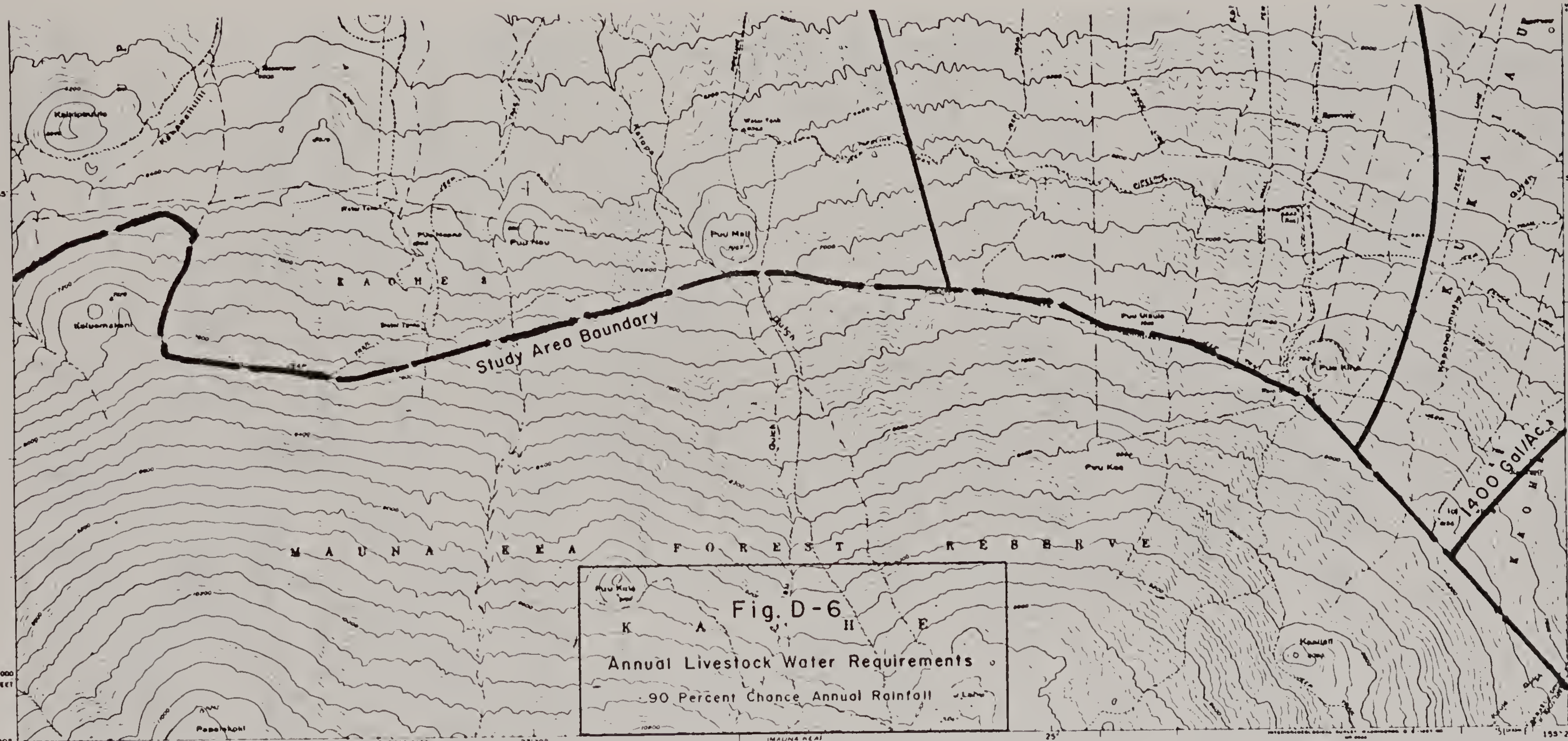


Fig. D-6

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



Mapped, edited, and published by the Geological Survey
Control by USGS and USC&GS
Topography from aerial photographs by multiplex methods
Aerial photographs taken 1954 Field check 1956
Polyconic projection. Old Hawaiian datum
10,000 foot grid based on Hawaiian coordinate system, zone 1
1000 meter Universal Transverse Mercator grid ticks, zone 5, shown in blue

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

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A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

ROAD CLASSIFICATION
Light-duty ______ Unimproved dirt ....

QUADRANGLE LOCATION

UMIKOA, HAWAII
N1952.5—W15522.5/7.5
1956

Fig. D-6

H-45

H-45

KEANAKOLU QUADRANGLE
HAWAII—ISLAND AND COUNTY OF HAWAII
7.5 MINUTE SERIES (TOPOGRAPHIC)

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Fig. D-7

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Control by USGS and USC&GS
Topography from aerial photographs by multiplex methods. Aerial photographs taken 1954. Field check 1956
Polyconic projection. Old Hawaiian datum
10,000-foot grid based on Hawaiian coordinate system, zone 1
1000-meter Universal Transverse Mercator grid ticks, zone 5, shown in blue
Unchecked elevations are shown in brown

APPROXIMATE MEAN DECLINATION, 1956

SCALE 1:24000

CONTOUR INTERVAL 40 FEET
DATUM IS MEAN SEA LEVEL

FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER 2, COLORADO OR WASHINGTON 25, D. C.
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

ROAD CLASSIFICATION
Medium-duty ——— Light-duty ———
Unimproved dirt - - - - - -

KEANAKOLU, HAWAII

1966

H-53

Fig. D-7

H-53

APPENDIX E

WATER HARVESTING CATCHMENT DESIGN

E-1

WATER HARVESTING CATCHMENT DESIGN

Figure E-1 and the following formula can be used to size and evaluate water harvesting catchments. Figure E-1 is only valid for hydrographic area 81, and is for 90 percent chance annual rainfall.

The two values that are related on Figure E-1 are Withdrawal Factor and Storage Factor. They are defined as follows:

Withdrawal Factor = WF

$$WF = \frac{1.60 \text{ (Use Rate gal./mo.)}}{\text{(Catchment Area ft.}^2\text{) (Mean Annual Rain in.)}} \qquad [1]$$

Storage Factor = SF

$$SF = \frac{1.60 \text{ (Storage Volume gal.)}}{\text{(Catchment Area ft.}^2\text{) (Mean Annual Rain in.)}} \qquad [2]$$

Using Figure E-1, the value of the Withdrawal Factor cannot exceed 0.07 and the value of the Storage Factor cannot exceed 0.34.

To calculate Use Rate or Withdrawal Rate in gallons per month, the above formulas can be written as follows:

$$\text{Use Rate gal./mo.} = \frac{\text{WF (Catchment Area ft.}^2\text{) (Mean Annual Rain in.)}}{1.60} \qquad [3]$$

or

$$\text{Use Rate gal./mo.} = \frac{\text{WF (Storage Volume gal.)}}{\text{SF}} \qquad [4]$$

To calculate Storage Volume in gallons, the formulas can be written as follows:

$$\text{Storage Volume gal.} = \frac{\text{SF (Catchment Area ft.}^2\text{) (Mean Annual Rain in.)}}{1.60} \qquad [5]$$

or

$$\text{Storage Volume gal.} = \frac{\text{SF (Use Rate gal./mo.)}}{\text{WF}} \qquad [6]$$

Since Catchment Area is in both the equation for SF and WF, it cannot be solved directly; it must be found by using a trial and error process knowing Use Rate and Storage Volume.

To calculate maximum Use Rate knowing Storage Volume, Catchment Area, and Mean Annual Rainfall:

1. Solve for SF using Equation [2],
2. Find WF from Figure E-1,
3. Solve for Use Rate using Equation [4].

To calculate minimum Storage Volume needed knowing Catchment Area, Use Rate, and Mean Annual Rainfall:

1. Solve for WF using Equation [1],
2. Find SF from Figure E-1,
3. Solve for Storage Volume using Equation [6].

To find the minimum Catchment Area needed knowing Storage Volume, Use Rate, Rate, and Mean Annual Rainfall:

1. Assume a Catchment Area,
2. Calculate WR using Equation [1],
3. Find SF from Figure E-1,
4. Calculate Storage using Equation [6],
5. Compare calculated Storage with known Storage,
6. Try another Catchment Area until one is found that results in the calculated Storage being approximately equal to the known Storage.

To find Storage Volume and Catchment needed knowing only the Use Rate and Mean Annual Rainfall:

1. Assume a value of WF,
2. Find SF from Figure E-1,
3. Calculate Storage Volume from Equation [6],
4. Calculate Catchment Area using Equation [1],
5. Try other values of WF, as there are an infinite number of solutions,
6. Choose the combination of Storage Volume and Catchment Area that appears the most economical to build for the Use Rate and Rainfall.

FIGURE E-1
Water Harvesting Catchment Design
90 Percent Chance Annual Rainfall
Hydrographic Area 81